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# Research on Diffraction Patterns of Smartphone Screens

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**Abstract:**

Smartphone screen is composed of pixels which are not of uniform size and arranged evenly. When illuminated by a laser, the reflected beam diffracts, producing a diffraction pattern with structure of mesh shape that exhibits characteristics similar to a two-dimensional reflection grating.

In this paper, the general diffraction formula of a two-dimensional non-uniform grating is derived, while a simplified form in a special case is explored. The influence of laser incidence angle on the diffraction pattern is analyzed. The diffraction patterns by formula calculation and Fourier transform are obtained using MATLAB simulation. The rationality of the derived formula is verified through simulation and experiments. Also, the pixel density of the smartphone screen is calculated based on the diffraction pattern obtained from the experiment. The application scenarios of the research results are proposed.

Comparing the discrepancy in diffraction patterns of different types of screens whose arrangements of sub pixels in smartphones are also different, the mechanism of grating diffraction is displayed directly. Theoretical calculations, simulations and experiments are applied for comparing and confirming each other.

**Keywords:** smartphone, grating diffraction, MATLAB simulation, pixel density

## I. Introduction

Light has many magical properties and often leads to interesting phenomena in daily life. For example, when the screens of electronic products around are lighted, there will be very beautiful patterns. Shining the flashlight on a television screen, colorful asterisk-shaped patterns will appear. Using a flashlight to illuminate a computer screen will have grid-like ripples appearing on the screen. When a laser pen shines on a smartphone screen, it will reflect many regularly arranged "points" on the wall. These patterns are all very beautiful and gorgeous, while these wonderful patterns cannot be observed directly on the screens of electronic products. Therefore, I often think about where these patterns come from and the reasons for their emergence.

Later on, I learned about the diffraction theory of light in physics courses. Light bypasses obstacles and deviates from a straight line to enter geometric shadows, casting an intricate pattern on the screen, which is called diffraction. After consulting materials, it was also learned that many electronic screens have regularly arranged pixel points, which can be regarded as grating.

The research of grating in the textbook is mostly based on multi-slit configuration called one-dimensional grating, which only considers the light and dark stripes in one direction. However, the pixel points on the smartphone screen are of rectangular shape, which will lead to brightness variation in both horizontal and vertical directions. When a laser is incident, the phone screen reflects the beam and diffraction occurs, resulting in a pattern similar to simple lattice diffraction.

In order to explore the formation of diffraction patterns on smartphone screens, this paper will address the following issues: (1) What is the structure of smartphone screens as grating? (2) How are the patterns of grating diffraction formed? (3) What should the pattern of grating diffraction on a smartphone screen look like? (4) Can we measure the properties of pixels on a smartphone screen through a grating pattern? Based on the above issues, this paper will conduct research and analysis on smart phone screen grating through theoretical derivation, software simulation and experimental measurement.

## 2. The Basic Properties of Smartphone Screens

In order to understand the pixel structure of smartphone screens and verify if the pixel lattice in the smartphone screen can truly be regarded as a two-dimensional grating and emit a "lattice" under laser irradiation, an optical microscope is used to observe the smartphone screen.

### 2.1 Classification of Smartphone Screens

According to the material of the screen, the mainstream smartphone screens in the current market can be divided into two types: LCD and OLED[1].

LCD refers to a liquid crystal display screen, with a bottom layer consisting of a backlight that emits white light. The middle layer consists of a liquid crystal layer, whose transparency changes with voltage. The top layer consists of a color filter. The middle liquid crystal layer can be opened and closed like a shutter under voltage control, adjusting the backlight intensity through it. Then the light passes through the color filter, forming a different proportion of red, green, and blue light, ultimately presents a colorful image on the screen.

OLED, also known as organic light-emitting diode, differs from LCD in principle in that it does not require backlight to illuminate, using light-emitting diodes instead. These light-emitting diodes can emit light independently as long as there is current flowing through. Each sub pixel is independent, and the three color light is combined to form a color image.

Due to different lighting principles, the commonly used pixel arrangement methods for two types of smartphone screens are also different. LCD screens often use standard RGB arrangement, with red, green, and blue filters of the same size as sub pixels, arranged side by side to form a single pixel. OLED screens are mostly arranged with the structure call diamond pixel, with each pixel composed of red-green and blue-green sub pixels.

## 2.2 Microscopic Observation of Smartphone Screens

In this experiment, three smartphones are studied, namely Honor 8, iPhone 7 Plus, and Vivo S9e. Before the experiment, I searched for the corresponding smartphone information on the official website, as shown in Table 2.1.

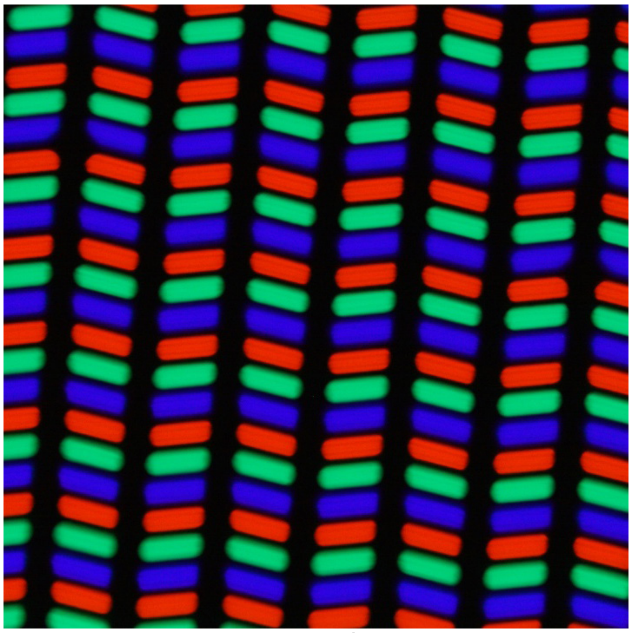
**Table 2.1 Parameters of Various Models of Smartphones on the Official Website**

| Screen parameters | Honor 8 | IPhone7 Plus | Vivo S9e |
|---|---|---|---|
| Screen size | 5.2 inches | 5.5 inches | 6.44 inches |
| Resolving power | 1920×1080 | 1920×1080 | 2404×1080 |
| Screen material | LCD | LCD | OLED |
| Pixel density | 423PPI | 401PPI | 408PPI |

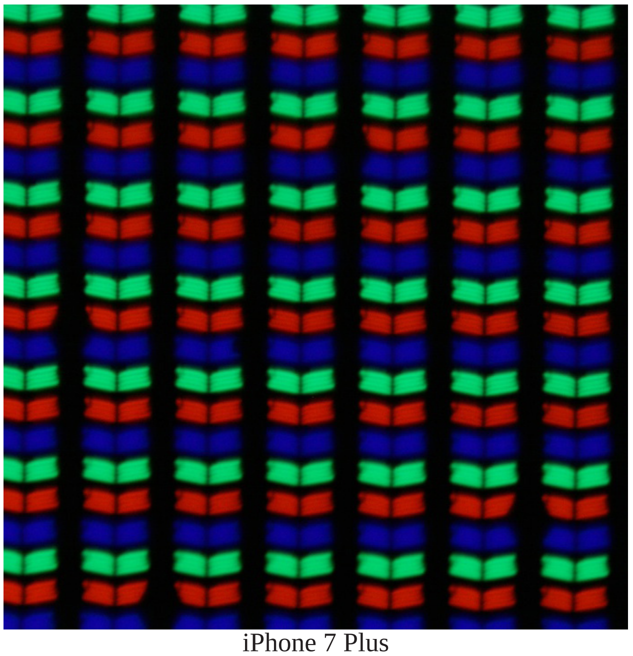
Observing smartphone screens of different models under the optical microscope (magnified by 200 times), the arrangement of pixels can be seen, as shown in Figure 2.2.

**Figure 2.1 Optical microscope**

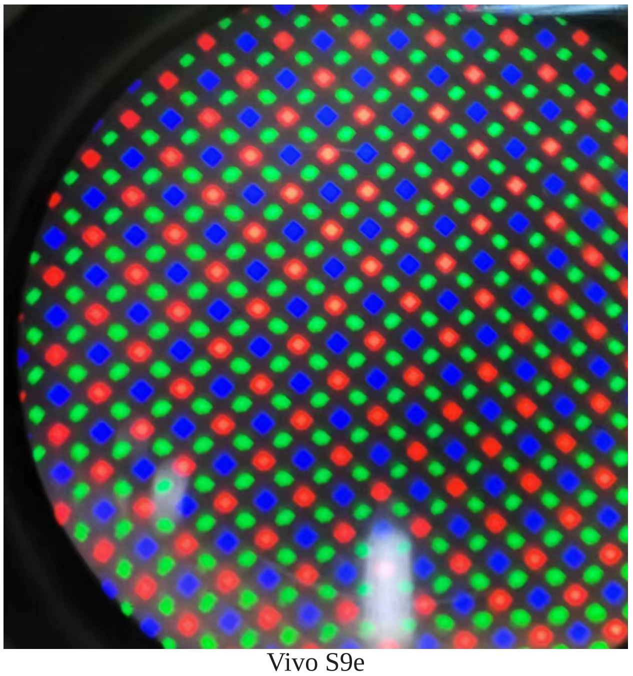
Observing the screens of these smartphones through the microscope, it can be found that Honor 8 and iPhone 7 Plus are both of LCD screens, and the sizes of the three pixels are very similar. However, the angles of the adjacent sub pixel filters of Honor 8 are different, while the filters of iPhone 7 Plus are V-shaped, with all sub pixels having the same shape and size. Vivo S9e adopts an OLED screen with diamond arranged pixels. The size and shape of sub pixels in different colors are not the same. The observed graphics are consistent with the information on the phone’s official website.



Honor 8



iPhone 7 Plus



Vivo S9e

**Figure 2.2 Screen pixel distribution under the microscope**

## 3. Theoretical Derivation and Simulation

### 3.1 Basic Theory of Grating Diffraction

When certain conditions are met, light has the ability to bypass obstacles and deviate from a straight line to enter geometric shadows, resulting in uneven distribution of light intensity on the screen. This phenomenon is called diffraction[2].

According to the Huygens-Fresnel principle, the combined vibration generated by a wavefront S is the superposition from the vibration generated by any area dS of the wavefront, i.e. Fresnel diffraction integral:

$$E = C\int \frac{K(\theta)A(Q)}{r} e^{i(kr-\omega t)} dS \tag{3-1}$$

where $C$ is the proportion coefficient, $K(\theta)$ is the tilt factor, $A(Q)$ is the distribution function, and $r$ is the optical path between the observation point and the wavefront.

Any diffraction device with spatial periodicity can be called a diffraction grating, which is a spectroscopic device, as shown in Figure 3.1. According to the formation position of the diffraction pattern, the grating can be divided into transmission grating and reflection grating. Currently, almost all gratings used in spectroscopic instruments are reflective blazed gratings. When a beam of certain wavelength is incident on the grating, a striped diffraction pattern is formed.

According to the distance between the light source and the opaque screen to the grating, diffraction phenomena can be divided into Fresnel diffraction and Fraunhofer diffraction. At least one diffraction with a finite distance between the light source and the screen to the grating is called Fresnel diffraction, while Fraunhofer diffraction refers to the diffraction phenomenon where the distance between the light source and the screen to the grating is infinite.

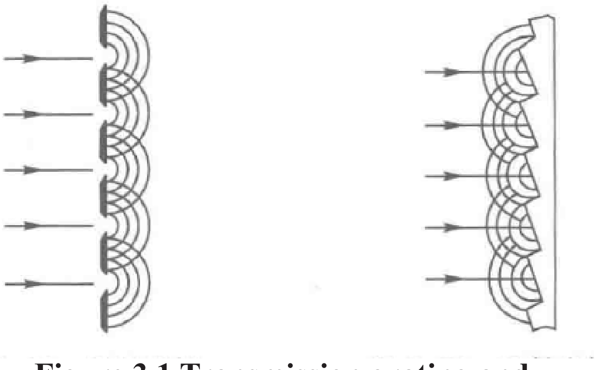


**Figure 3.1 Transmission grating and diffraction grating**

For a uniform one-dimensional planar grating, the diffraction formula is:

$$E = A_0 \frac{\sin(\frac{\pi b \sin\theta}{\lambda})}{\frac{\pi b \sin\theta}{\lambda}} \cdot \frac{\sin N(\frac{\pi b \sin\theta}{\lambda})}{\sin(\frac{\pi d \sin\theta}{\lambda})} \cdot e^{i[\pi \frac{b+(N-1)d}{\lambda}\sin\theta - \omega t} \quad (3\text{-}2)$$

Where $A_0$ is the amplitude of the light source, $b$ is the width of the narrow slit of the grating, $d$ is the distance between the two slits, i.e. the grating constant, $\lambda$ is the wavelength of the incident light, $N$ is the number of slits of the grating, and $\theta$ is the diffraction angle.

Let $u = \frac{\pi b \sin\theta}{\lambda}, v = \frac{\pi d \sin\theta}{\lambda}$, the optical intensity equation can be written as:

$$I_p = A_0^2 \frac{\sin^2 u}{u} \cdot \frac{\sin^2 Nv}{\sin^2 v} \quad (3\text{-}3)$$

Grating diffraction can actually be understood as a combination of single slit diffraction and multi beam interference phenomena. In equation (3-3), $\frac{\sin^2 u}{u}$ originates from single slit diffraction, which is the contour of the entire diffraction pattern and is called the single slit diffraction factor. $\frac{\sin^2 Nv}{\sin^2 v}$ originates from the inter slit interference of multiple beams and is called the inter slit interference factor.

The interference factor affects the position of each maximum. When the optical path difference of the light emitted from adjacent slits is an integer multiple of the wavelength of the light, the two beams have the same phase, and interference occurs, resulting in bright spots. As shown in Figure 3.2, when a plane wave is incident perpendicular to the grating plane, the incident angle between the ray and the normal of the groove surface is $\theta_B$, which satisfies:

$$d \sin\theta_B = k\lambda, k = 0, \pm 1, \pm 2, \cdots\cdots \quad (3\text{-}4)$$

At this point, the maximum relative intensity is obtained. The function (3-4) is called grating equation, and the integer $k$ is called the series of spectral lines.

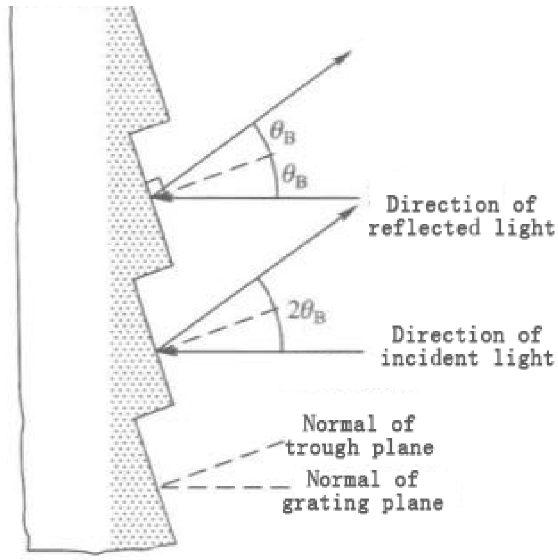



**Figure 3.2 Grating diffraction diagram**

As shown in Figure 3.3, when the diffraction angle is small, it can be approximately assumed that the diffraction angle $\theta$ satisfies $\sin\theta \approx \tan\theta = \frac{lk}{L}$, then equation (3-5) is derived:

$$d = \frac{\lambda L}{\Delta l} \quad (3\text{-}5)$$

Where $\Delta l$ is the distance between adjacent spectral lines.

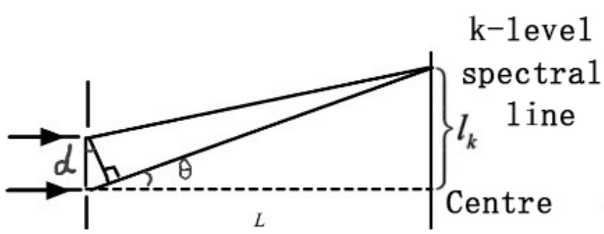



**Figure 3.3 Schematic diagram of diffraction with small diffraction angle**

The case of vertical incidence is discussed above. If a parallel beam is obliquely incident on the grating, the angle between the incident direction and the normal of the grating plane is $\theta_0$.

As shown in Figure 3.4, when parallel light is obliquely incident, if the incident and diffracted rays are on the same side of the normal of the grating, $\theta$ and $\theta_0$ are of the same sign. The optical path difference is $\Delta = d(\sin\theta + \sin\theta_0)$, then the grating equation is:

$$d(\sin\theta + \sin\theta_0) = k\lambda, k = 0, \pm1, \pm2, ...... \quad (3\text{-}6)$$

Similarly, as shown in Figure 3.5, if the incident and diffracted rays are on the opposite side of the grating normal, the grating equation is:

$$d(\sin\theta - \sin\theta_0) = k\lambda, k = 0, \pm1, \pm2, ...... \quad (3\text{-}7)$$

According to the formula above, when the incident light and diffracted light are on the same side of the normal, the larger the angle between the incident light and the normal, the smaller the diffraction angle, the closer the distance between the two maxima, and the denser the bright spots. When the incident light and diffracted light are on both sides of the normal, the larger the angle between the incident light and the normal, the rarer the bright spots. The above discussion is about the case of a transmission grating, and the incident and diffracted light of the reflection grating must be on different sides of the normal, that is, the larger the incident angle, the sparser the diffraction pattern bright spots of the smartphone screen.

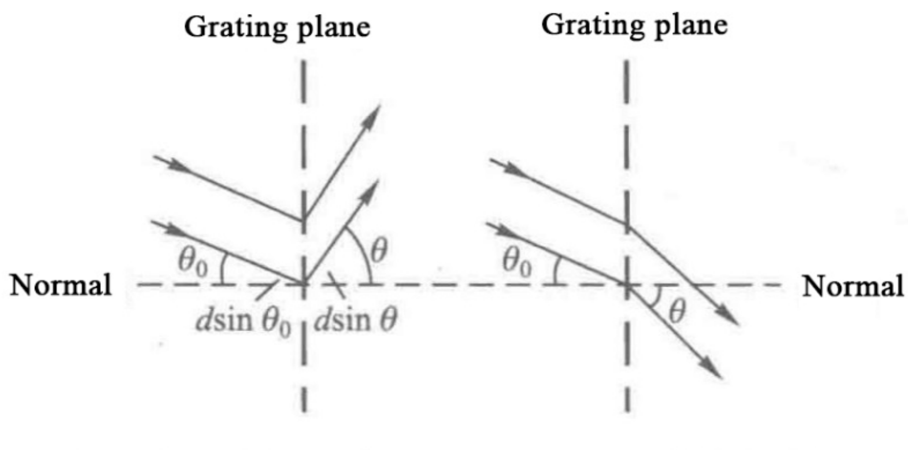



**Figure 3.4 Incident and diffracted rays on the same side of the normal of the grating plane**

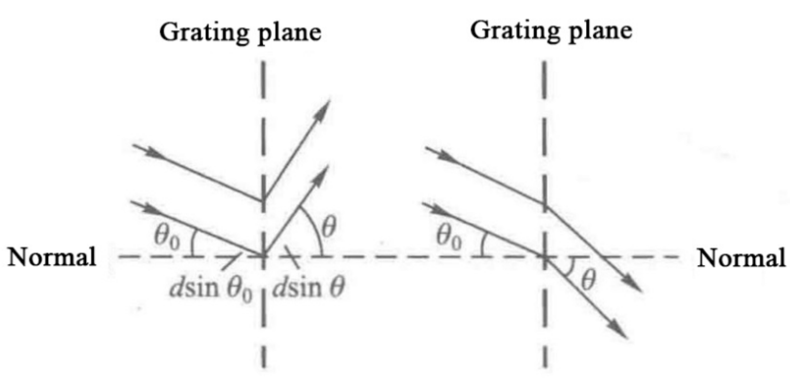



**Figure 3.5 Incident and diffracted rays on the opposite side of the normal of the grating plane**

### 3.2 Calculation Method for Pixel Density PPI of Smartphone Screens

Different smartphone screens are composed of tiny red, blue, and green display units arranged periodically. The smallest unit is called a pixel, and this periodic arrangement is equivalent to a raster.

PPI, also known as pixels per inch, represents the number of pixels per inch on the diagonal, in units of 1/in. The calculation formula is:

$$PPI = \frac{\sqrt{N_x^2 + N_y^2}}{L} \tag{3-8}$$

where is $N_x$ the number of pixels in the horizontal direction of the phone, $N_y$ is the number of pixels in the vertical direction of the phone, and $L$ is the diagonal length of the screen.

If the width of the smartphone screen is $x$ and the length is $y$, then the number of pixels obtained from geometric relationships on each direction is $N_x = \frac{x}{d}$ and $N_y = \frac{y}{d}$.

PPI can be obtained by substituting equation (3-8) as follows:

$$PPI = \frac{\sqrt{\frac{x^2}{d^2} + \frac{y^2}{d^2}}}{\sqrt{x^2 + y^2}} = \frac{1}{d} \tag{3-9}$$

The unit of $d$ is usually meter, which can be obtained by converting it to PPI common units:

$$PPI = \frac{1}{39.37d} \tag{3-10}$$

As long as the grating constant d of the smartphone screen is obtained, the PPI of the smartphone screen can be calculated.

### 3.3 Derivation of the Optical Intensity Equation for Two-Dimensional Diffraction Grating

When the diffraction angle is small, a two-dimensional grating can be understood as the superposition of two perpendicular and orthogonal one-dimensional gratings, which will generate diffraction and superposition in the two orthogonal dimensions, and each dimension will be modulated by the interference factor and diffraction factor. The uniform two-dimensional grating Fraunhofer diffraction intensity distribution formula is:

$$I_p = A_0^2 \cdot \frac{\sin^2 u_x}{u_x^2} \cdot \frac{\sin^2 u_y}{u_y^2} \cdot \frac{\sin^2 Nv_x}{\sin^2 v_x} \cdot \frac{\sin^2 Nv_y}{\sin^2 v_y} \tag{3-11}$$

Obviously, when considering the intensity distribution of a two-dimensional grating, it can be decomposed into two orthogonal directions and derived separately, and then the intensity can be synthesized into a plane.

Firstly, the formula for the diffraction intensity distribution of diamond structure screens is derived. Observing the pixel composition under the microscope, it can be roughly believed that two rectangular green pixels, one slightly larger square blue pixel, and one slightly smaller square red pixel can form one pixel unit, as shown in Figure 3.6 below. The smartphone screen is composed of multiple same pixel units. Let the blue pixel have a side length of $a$, the red pixel have a side length of, $b$ the long side of the green pixel have a side length of $c_1$, and the short side have a side length of $c_2$, obviously $a > c_1 > b > c_2$.

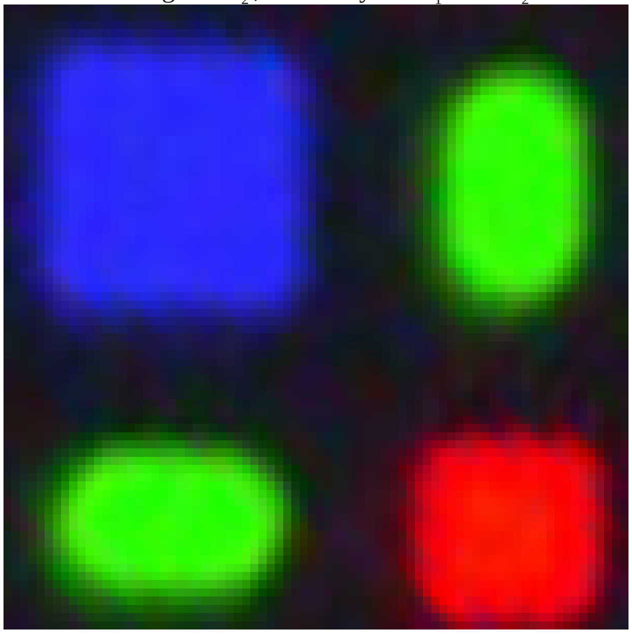


**Figure 3.6 Schematic diagram of pixel unit**

Firstly, consider a relatively simple situation. If $a = c_1 > b = c_2$, we can consider the x and y directions separately, analyzing them as non-uniform gratings with periodic changes in slit width.

The vibration equation of the non-uniform grating in the x-direction can be obtained from equation (3-2) as follows:

$$E_x = e^{-i\omega t}[\frac{A_0^{'}}{a}\int_0^a e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx + \frac{A_0}{b}\int_{a+d_1}^{a+d_1+b} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx$$
$$+\frac{A_0^{'}}{a}\int_d^{d+a} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx + \frac{A_0}{b}\int_{d+a+d_1}^{d+a+d_1+b} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx + \cdots\cdots \tag{3-12}$$
$$+\frac{A_0^{'}}{a}\int_{(N-1)d}^{(N-1)d+a} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx + \frac{A_0}{b}\int_{(N-1)d+a+d_1}^{(N-1)d+a+d_1+b} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx]$$

where $d_1$ is the distance between two adjacent edges that are close to each other, i.e.

$$d_1 = \frac{d-a-b}{2} \tag{3-13}$$

For uniform light, the intensity of incident light per unit width is the same, which should be $\frac{A_0}{b} = \frac{A_0^{'}}{a}$.

The above equation can be divided into the sum of two proportional sequences:

$$E_{x1} = e^{-i\omega t}[\frac{A_0^{'}}{a}\int_0^a e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx + \frac{A_0^{'}}{a}\int_d^{d+a} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx + \cdots\cdots$$
$$+\frac{A_0^{'}}{a}\int_{(N-1)d}^{(N-1)d+a} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx] \tag{3-14}$$

and

$$E_{x2} = e^{-i\omega t}[\frac{A_0}{b}\int_{a+d_1}^{a+d_1+b} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx + \frac{A_0}{b}\int_{d+a+d_1}^{d+a+d_1+b} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx + \cdots\cdots$$
$$+\frac{A_0}{b}\int_{(N-1)d+a+d_1}^{(N-1)d+a+d_1+b} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx] \tag{3-15}$$

To calculate $E_{x1}$, for item n, there is:

$$\int_{(n-1)d}^{(n-1)d+a} e^{i\frac{2\pi}{\lambda}x\sin\theta_x}dx = \frac{1}{i\frac{2\pi}{\lambda}\sin\theta_x}\cdot e^{i\frac{2\pi}{\lambda}x\sin\theta_x}\Big|_{(n-1)d}^{(n-1)d+a}$$
$$= \frac{1}{i\frac{2\pi}{\lambda}\sin\theta_x}\cdot e^{i\frac{2\pi}{\lambda}(n-1)d\sin\theta_x}\cdot(e^{i\frac{2\pi}{\lambda}a\sin\theta_x}-1)$$
$$= \frac{1}{\frac{\pi}{\lambda}\sin\theta_x}\cdot e^{i\frac{2\pi}{\lambda}(n-1)d\sin\theta_x}\cdot e^{i\frac{\pi}{\lambda}a\sin\theta_x}\frac{\cdot(e^{i\frac{\pi}{\lambda}a\sin\theta_x}-e^{-i\frac{\pi}{\lambda}a\sin\theta_x})}{2i} \tag{3-16}$$
$$= e^{i\frac{\pi}{\lambda}[2(n-1)d+a]\sin\theta_x}\cdot\frac{\sin(\frac{\pi}{\lambda}a\sin\theta_x)}{\frac{\pi}{\lambda}a\sin\theta_x}$$

The only thing related to n in the equation is $e^{i\frac{\pi}{\lambda}[2(n-1)d+a]\sin\theta_x}$, which is an N-term proportional sequence with a first term $e^{i\frac{\pi}{\lambda}a\sin\theta_x}$ and a common ratio $e^{i\frac{\pi}{\lambda}2d\sin\theta_x}$, and its sum is:

$$e^{i\frac{\pi}{\lambda}a\sin\theta_x}\cdot\frac{1-e^{i\frac{2\pi}{\lambda}Nd\sin\theta_x}}{1-e^{i\frac{2\pi}{\lambda}d\sin\theta_x}} = e^{i\frac{\pi}{\lambda}a\sin\theta_x}\cdot e^{i\frac{\pi}{\lambda_1}(N-1)d\sin\theta_x}\cdot\frac{\sin(N\frac{\pi}{\lambda}d\sin\theta_x)}{\sin(\frac{\pi}{\lambda}d\sin\theta_x)} \tag{3-17}$$

From above it can be concluded that:

$$E_{x1} = e^{-i\omega t} \cdot \frac{A_0^{'}}{a} \cdot \frac{\sin(\frac{\pi}{\lambda} a \sin\theta_x)}{\frac{\pi}{\lambda}\sin\theta_x} \cdot e^{i\frac{\pi}{\lambda} a \sin\theta_x} \cdot e^{i\frac{\pi}{\lambda_1}(N-1)d\sin\theta_x} \cdot \frac{\sin(N\frac{\pi}{\lambda} d\sin\theta_x)}{\sin(\frac{\pi}{\lambda} d\sin\theta_x)}$$

$$= A_0^{'} \cdot \frac{\sin(\frac{\pi}{\lambda} a \sin\theta_x)}{\frac{\pi}{\lambda} a \sin\theta_x} \cdot \frac{\sin(N\frac{\pi}{\lambda} d\sin\theta_x)}{\sin(\frac{\pi}{\lambda} d\sin\theta_x)} \cdot e^{i\frac{\pi}{\lambda}[a+(N-1)d]\sin\theta_x - i\omega t} \tag{3-18}$$

The derivation of $E_{x2}$ is similar with $E_{x1}$, and the integral term of the nth term is:

$$\int_{(n-1)d+a+d_1}^{(n-1)d+a+d_1+b} e^{i\frac{2\pi}{\lambda}x\sin\theta_x} dx = \frac{1}{i\frac{2\pi}{\lambda}\sin\theta_x} \cdot e^{i\frac{2\pi}{\lambda}[(n-1)d+a+d_1]\sin\theta_x} \cdot (e^{i\frac{2\pi}{\lambda}b\sin\theta_x} - 1)$$

$$= \frac{\sin(\frac{\pi}{\lambda} b \sin\theta_x)}{\frac{\pi}{\lambda} b \sin\theta_x} \cdot e^{i\frac{\pi}{\lambda}[2a+b+2d_1+(N-1)d]\sin\theta_x} \cdot \frac{\sin(N\frac{\pi}{\lambda} d\sin\theta_x)}{\sin(\frac{\pi}{\lambda} d\sin\theta_x)} \tag{3-19}$$

Correspondingly, there is:

$$E_{x2} = e^{-i\omega t} \cdot \frac{A_0}{b} \cdot \frac{\sin(\frac{\pi}{\lambda} b \sin\theta_x)}{\frac{\pi}{\lambda}\sin\theta_x} \cdot e^{i\frac{\pi}{\lambda}(2a+b+2d_1)\sin\theta_x} \cdot e^{i\frac{\pi}{\lambda_1}(N-1)d\sin\theta_x} \cdot \frac{\sin(N\frac{\pi}{\lambda} d\sin\theta_x)}{\sin(\frac{\pi}{\lambda} d\sin\theta_x)}$$

$$= A_0 \cdot \frac{\sin(\frac{\pi}{\lambda} b \sin\theta_x)}{\frac{\pi}{\lambda} b \sin\theta_x} \cdot \frac{\sin(N\frac{\pi}{\lambda} d\sin\theta_x)}{\sin(\frac{\pi}{\lambda} d\sin\theta_x)} \cdot e^{i\frac{\pi}{\lambda}[2a+b+2d_1+(N-1)d]\sin\theta_x - i\omega t} \tag{3-20}$$

Solve with $E_x$:

$$E_x = E_{x1} + E_{x2}$$

$$= A_0 \cdot \frac{\sin(N\frac{\pi}{\lambda} d\sin\theta_x)}{\sin(\frac{\pi}{\lambda} d\sin\theta_x)} \cdot \{\frac{a}{b} \cdot \frac{\sin(\frac{\pi}{\lambda} a \sin\theta_x)}{\frac{\pi}{\lambda} a \sin\theta_x} \cdot e^{i\frac{\pi}{\lambda}[a+(N-1)d]\sin\theta_x - i\omega t} \tag{3-21}$$

$$+ \frac{\sin(\frac{\pi}{\lambda} b \sin\theta_x)}{\frac{\pi}{\lambda} b \sin\theta_x} \cdot e^{i\frac{\pi}{\lambda}[2a+b+2d_1+(N-1)d]\sin\theta_x - i\omega t}\}$$

In the formula, $A_0^2 \cdot \frac{\sin^2(N\frac{\pi}{\lambda} d\sin\theta_x)}{\sin^2(\frac{\pi}{\lambda} d\sin\theta_x)}$ can be regarded as a coefficient, and the sum in parentheses can be regarded as the sum of two coherent beams of light. The intensity of the addition light is:

$$I_x = A_0^2 \cdot \frac{\sin^2(N\frac{\pi}{\lambda}d\sin\theta_x)}{\sin^2(\frac{\pi}{\lambda}d\sin\theta_x)} \cdot \{\frac{a^2}{b^2} \cdot \frac{\sin^2(\frac{\pi}{\lambda}a\sin\theta_x)}{(\frac{\pi}{\lambda}a\sin\theta_x)^2} + \frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta_x)}{(\frac{\pi}{\lambda}b\sin\theta_x)^2}$$

$$+2 \cdot \frac{a}{b} \cdot \frac{\sin(\frac{\pi}{\lambda}a\sin\theta_x)}{\frac{\pi}{\lambda}a\sin\theta_x} \cdot \frac{\sin(\frac{\pi}{\lambda}b\sin\theta_x)}{\frac{\pi}{\lambda}b\sin\theta_x} \cdot \cos[\frac{\pi}{\lambda}(a+b+2d_1)\sin\theta_x]\}$$

$$= A_0^2 \cdot \frac{\sin^2(N\frac{\pi}{\lambda}d\sin\theta_x)}{\sin^2(\frac{\pi}{\lambda}d\sin\theta_x)} \cdot [\frac{\sin^2(\frac{\pi}{\lambda}a\sin\theta_x)}{(\frac{\pi}{\lambda}a\sin\theta_x)^2} + \frac{a^2}{b^2} \cdot \frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta_x)}{(\frac{\pi}{\lambda}b\sin\theta_x)^2}$$

$$+2 \cdot \frac{a}{b} \cdot \frac{\sin(\frac{\pi}{\lambda}a\sin\theta_x)}{\frac{\pi}{\lambda}a\sin\theta_x} \cdot \frac{\sin(\frac{\pi}{\lambda}b\sin\theta_x)}{\frac{\pi}{\lambda}b\sin\theta_x} \cdot \cos(\frac{\pi}{\lambda}d\sin\theta_x)] \tag{3-22}$$

Equation (3-22) is the general form for the intensity of one-dimensional non-uniform gratings with alternating slit widths.

Based on the microscopic pixel map, it can be assumed that $a = 2b$ and the distance between the center points of any two adjacent pixels of the same color should be $d = 6b$ .Equation (3-22) can be further simplified as:

$$I_x = A_0^2 \cdot \frac{\sin^2(N\frac{\pi}{\lambda}6b\sin\theta_x)}{\sin^2(\frac{\pi}{\lambda}6b\sin\theta_x)} \cdot \{4 \cdot \frac{\sin^2(\frac{\pi}{\lambda}2b\sin\theta_x)}{(\frac{\pi}{\lambda}2b\sin\theta_x)^2} + \frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta_x)}{(\frac{\pi}{\lambda}b\sin\theta_x)^2}$$

$$+4 \cdot \frac{\sin(\frac{\pi}{\lambda}2b\sin\theta_x)}{\frac{\pi}{\lambda}2b\sin\theta_x} \cdot \frac{\sin(\frac{\pi}{\lambda}b\sin\theta_x)}{\frac{\pi}{\lambda}b\sin\theta_x} \cdot \cos(\frac{\pi}{\lambda}6b\sin\theta_x)\}$$

$$=A_0^2 \cdot \frac{\sin^2(N\frac{\pi}{\lambda}6b\sin\theta_x)}{\sin^2(\frac{\pi}{\lambda}6b\sin\theta_x)} \cdot \{4 \cdot \frac{4\sin^2(\frac{\pi}{\lambda}b\sin\theta_x)\cos^2(\frac{\pi}{\lambda}b\sin\theta_x)}{4(\frac{\pi}{\lambda}b\sin\theta_x)^2} + \frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta_x)}{(\frac{\pi}{\lambda}b\sin\theta_x)^2} \tag{3-23}$$

$$+4 \cdot \frac{2\sin(\frac{\pi}{\lambda}b\sin\theta_x)\cos(\frac{\pi}{\lambda}b\sin\theta_x)}{\frac{\pi}{\lambda}2b\sin\theta_x} \cdot \frac{\sin(\frac{\pi}{\lambda}b\sin\theta_x)}{\frac{\pi}{\lambda}b\sin\theta_x} \cdot \cos(\frac{\pi}{\lambda}6b\sin\theta_x)\}$$

$$= A_0^2 \cdot \frac{\sin^2(N\frac{\pi}{\lambda}6b\sin\theta_x)}{\sin^2(\frac{\pi}{\lambda}6b\sin\theta_x)} \cdot \frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta_x)}{(\frac{\pi}{\lambda}b\sin\theta_x)^2}$$

$$\cdot[1 + 4 \cdot \cos^2(\frac{\pi}{\lambda}b\sin\theta_x) + 4 \cdot \cdot\cos(\frac{\pi}{\lambda}b\sin\theta_x) \cdot \cos(\frac{\pi}{\lambda}6b\sin\theta_x)]$$

This expression can be divided into three parts: $\frac{\sin^2(N\frac{\pi}{\lambda}6b\sin\theta_x)}{\sin^2(\frac{\pi}{\lambda}6b\sin\theta_x)}$ and $\frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta_x)}{(\frac{\pi}{\lambda}b\sin\theta_x)^2}$ are the interference factor between slots and the diffraction factor of a single slot, while factor

$$1 + \cos^2(\frac{\pi}{\lambda}b\sin\theta_x) + 2 \cdot \cos(\frac{\pi}{\lambda}b\sin\theta_x) \cdot \cos(\frac{\pi}{\lambda}6b\sin\theta_x)$$

reflects the influence of two gratings on each other. When the two slit widths of an uneven grating meet certain conditions, it can be simplified and referred to as the grating influence factor.

The diffraction situation in the y direction is the same as that in the x direction, and the intensity distribution formula for two-dimensional grating diffraction is $I = I_x \cdot I_y$:

$$I = A_0^2 \cdot \frac{\sin^2(N\frac{\pi}{\lambda}6b\sin\theta_x)}{\sin^2(\frac{\pi}{\lambda}6b\sin\theta_x)} \cdot \frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta_x)}{(\frac{\pi}{\lambda}b\sin\theta_x)^2}$$

$$\cdot \frac{\sin^2(N\frac{\pi}{\lambda}6b\sin\theta_y)}{\sin^2(\frac{\pi}{\lambda}6b\sin\theta_y)} \cdot \frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta_y)}{(\frac{\pi}{\lambda}b\sin\theta_y)^2} \tag{3-24}$$

$$\cdot[1 + 4\cdot\cos^2(\frac{\pi}{\lambda}b\sin\theta_x) + 4\cdot\cdot\cos(\frac{\pi}{\lambda}b\sin\theta_x)\cdot\cos(\frac{\pi}{\lambda}6b\sin\theta_x)]$$

$$\cdot[1 + 4\cdot\cos^2(\frac{\pi}{\lambda}b\sin\theta_y) + 4\cdot\cdot\cos(\frac{\pi}{\lambda}b\sin\theta_y)\cdot\cos(\frac{\pi}{\lambda}6b\sin\theta_y)]$$

## 3.4 MATLAB Simulation

Based on the above derivation function, MATLAB code is made up to simulate one-dimensional uniform grating, two-dimensional uniform grating, one-dimensional non-uniform grating and two-dimensional non-uniform grating, and obtain the following simulation graphics.

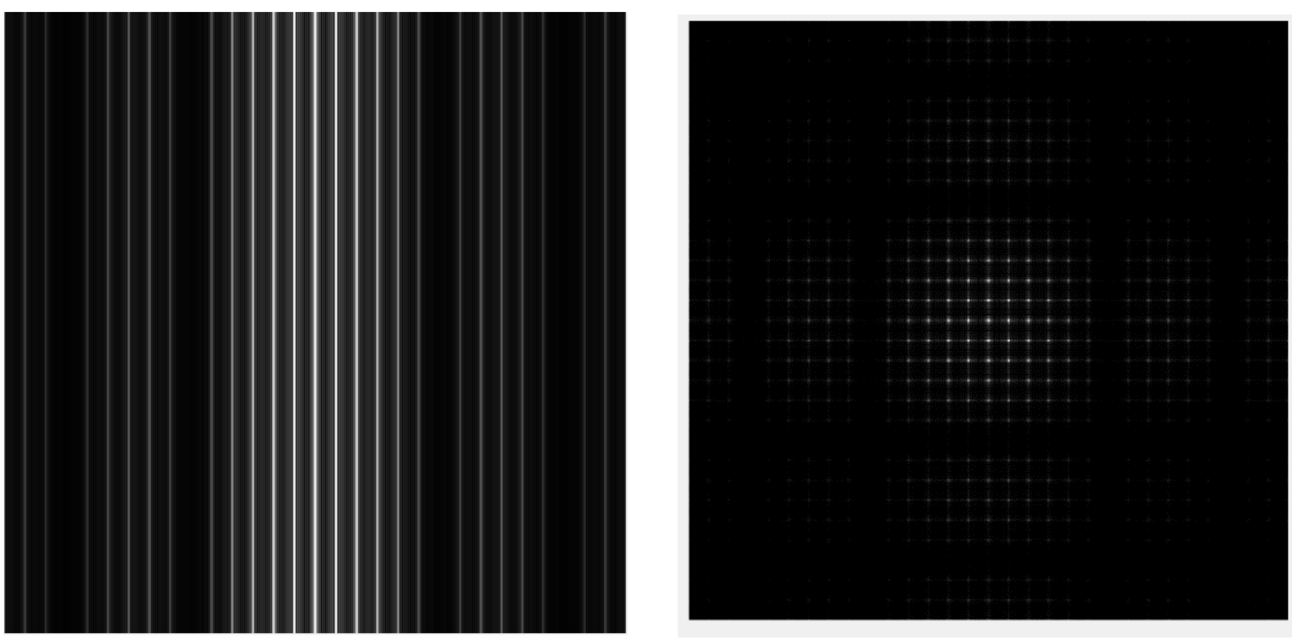


**Figure 3.7 Simulation diffraction patterns of one-dimensional and two-dimensional uniform gratings**

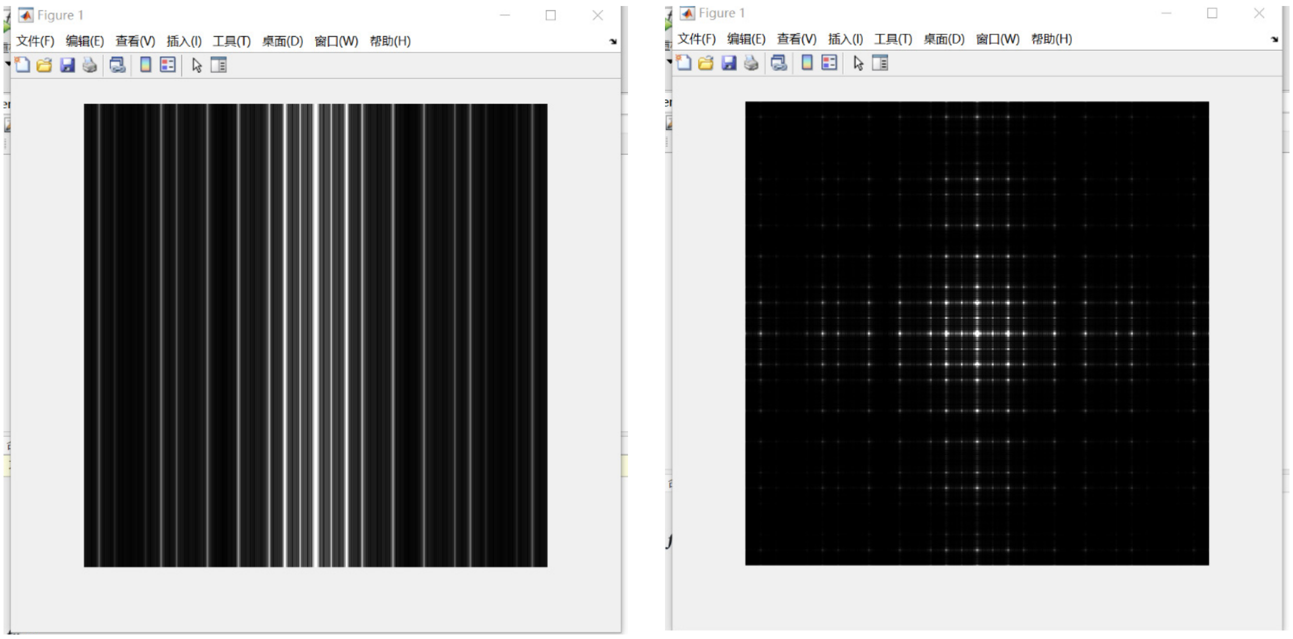



**Figure 3.8 Simulation diffraction patterns of one-dimensional and two-dimensional non-uniform gratings**

It can be seen that there are significant differences between uniform and non-uniform diffraction patterns in both one-dimensional and two-dimensional gratings. For two-dimensional gratings, the overall shape of their diffraction pattern still presents a cross-shaped pattern, with some diffraction points strengthened and dark spots appearing in some positions. This is the result of modulation by the grating influence factor, which physically reflects the influence of grating non-uniformity.

## 3.5 More Accurate Pattern Simulation Based on Fourier Transformation

After observing the image, I believe that the non-uniformity of the grating can have a significant impact on the diffraction pattern. However, in the process of deriving phone pixels, the assumption was used to erase some of the non-uniform properties. Will this affect the approximate results? This section delves deeper into this issue.

Firstly, the complex amplitude method is adopted to derive the equation, but at this time, when examining the x-direction, there are two types of non-uniform gratings with different periods, making it even more difficult to solve directly. Through reviewing textbooks, it is found that there is another method for simulating grating intensity: transforming based on Fourier methods.

The aperture function should be introduced:

$$A(x) = \begin{cases} 1, transparent \\ 0, opaque \end{cases} \tag{3-25}$$

The vibration function of any hole (or gap) is:

$$E_x = e^{-i\omega t} \frac{A_0}{a} \int_{-\infty}^{\infty} A(x) \cdot e^{i\frac{2\pi}{\lambda} x \sin\theta} dx \tag{3-26}$$

The function $\int_{-\infty}^{\infty} A(x) \cdot e^{i\frac{2\pi}{\lambda} x \sin\theta} dx$ has a form similar to the inverse Fourier transform, and in practical calculations, the Fourier transform is used to characterize this change, that is, in Fraunhofer diffraction, the optical intensity of the diffraction pattern is the Fourier transform of the aperture function. Based on this conclusion, when solving the illumination intensity of grating diffraction patterns, the aperture function can be written first, and then the amplitude can be calculated using Fourier transform.

Based on this approach, a new simulation method is adopted. Firstly, the aperture function of the phone screen pixels is obtained. Then its Fourier transform is solved. Finally, a simulation pattern can be drawn. By using this method, simulated diffraction patterns of two types of LCD screens and OLED screen can be drawn [3].

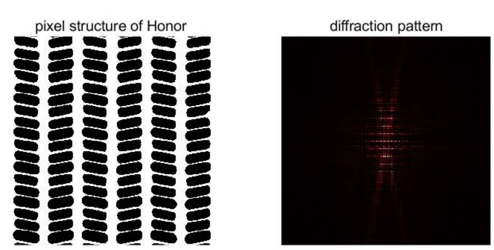



**Figure 3.9 Pixel distribution and diffraction pattern of Honor 8 screen**

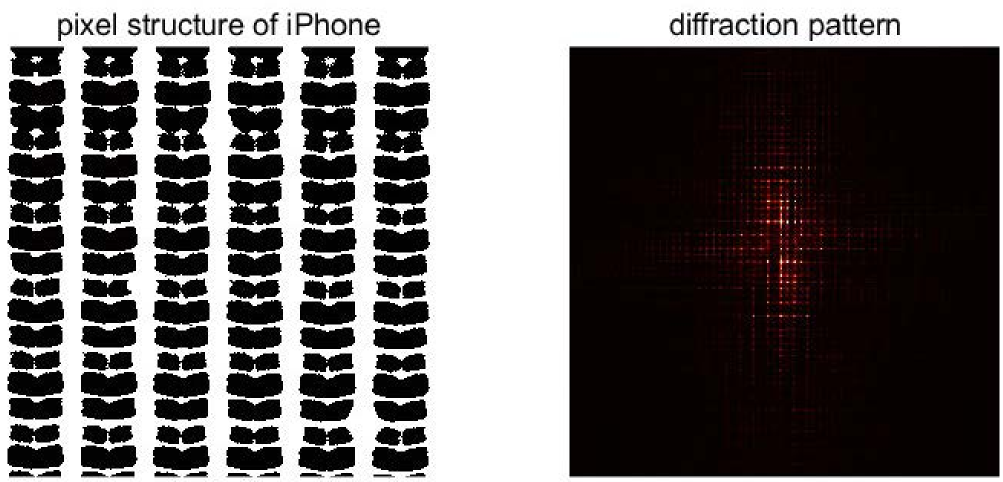



**Figure 3.10 Pixel distribution and diffraction pattern of iPhone 7 Plus screen**

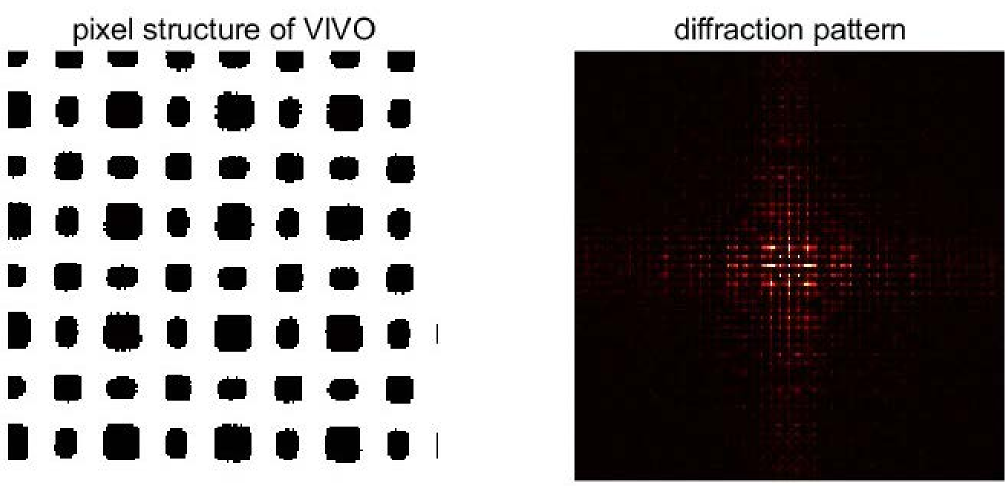



**Figure 3.11 Pixel distribution and diffraction pattern of VIVO screen**

It can be seen that the structure of the OLED screen is merely the same as the previous simulation result, indicating that a small difference in non-uniformity has little impact on the diffraction pattern. Although there are many burrs, depressions, and other uneven spots in the binary pixel distribution map, the basic structure of the diffraction pattern is still consistent with the theoretical derivation result. In other words, when the difference in different slit widths of non-uniform gratings is very small, non-uniform grating diffraction can be approximated as uniform grating diffraction.

The simulation effect of LCD screens is significantly different from that of OLED screens. In the diffraction pattern formed by the Honor 8 screen, there are inclined and divergent X-shaped stripes, which may be formed because each column of grating has a certain tilt angle. The diffraction pattern formed by the iPhone 7 Plus screen is relatively uniform, possibly due to the central symmetry of the shape of each sub pixel.

IV. Diffraction Experiment on Smartphone Screen

## 4.1 Preparation of Experimental Equipment

The factors that affect the grating pattern include incident angle, projection distance, incident light wavelength, and so on. To test the effect of incident light wavelength on the diffraction pattern, I select a red laser pen with a wavelength of 650 nm and a power of 40 mW, as well as a green laser pen with a wavelength of 532 nm and a power of 70mW, as shown in Figure 4.1.

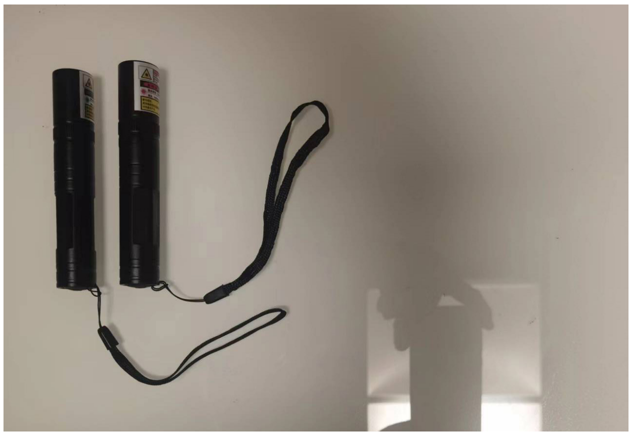


**Figure 4.1 Selected laser pens**

By shining the laser directly on the wall, the laser points shown in Figure 4.2 can be seen.

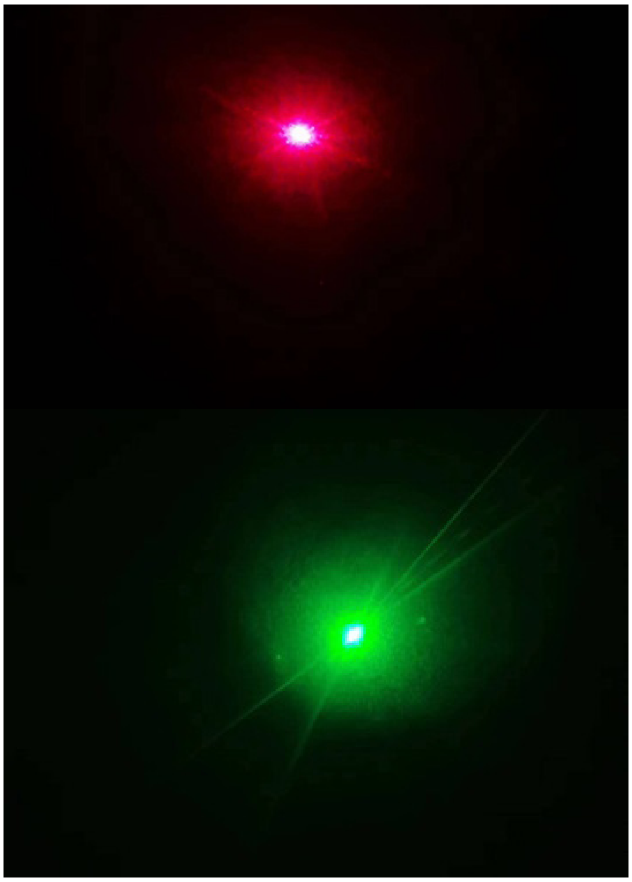


**Figure 4.2: Pattern of laser directly shining on the wall**

In a dark environment, using a laser to illuminate a smartphone screen can clearly lead to the appearance of grid shaped patterns on the wall, indicating that the experiment is feasible. The smartphone screen can indeed serve as a two-dimensional reflection grating.

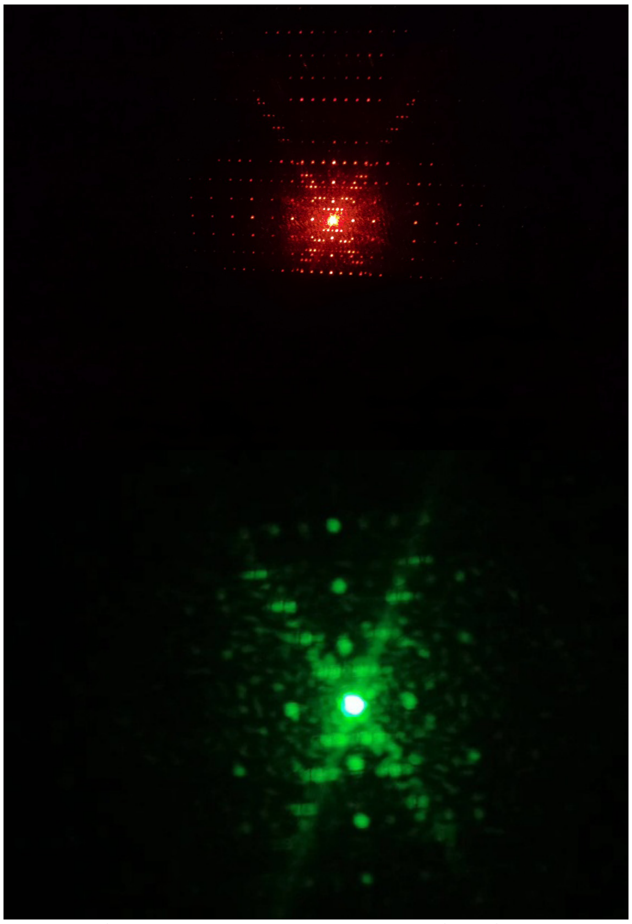


**Figure 4.3 Rough schematic of the preliminary experiment**

In order to further study the influence of factors such as incident angle and meet various horizontal and vertical requirements in diffraction experiments, I build an experimental platform. The phone is placed on the phone stand, using a triangular plate to measure its verticality. After adjustment, it is fixed with tape. Paste a piece of printing paper onto a movable board as a display screen, punch holes in the display screen, pad some books and printing papers according to the actual height of the hole, and adjust the number of printing paper sheets so that the laser generated by the laser pen can pass through the hole and shine on the phone screen. Adjust the angle of the display screen, using a triangular plate and a tape measure to make it parallel to the phone screen and 50 cm away from the phone screen. The laser shines through a small hole on the phone screen, causing diffraction and then reflecting the diffraction pattern onto the display screen. If the incident angle of the laser need to be changed, the phone holder to the corresponding angle can be simply rotated, and then the display screen  is placed in a position parallel to the phone screen. The top view (vertical state) of the experimental platform is shown in Figure 4.4.

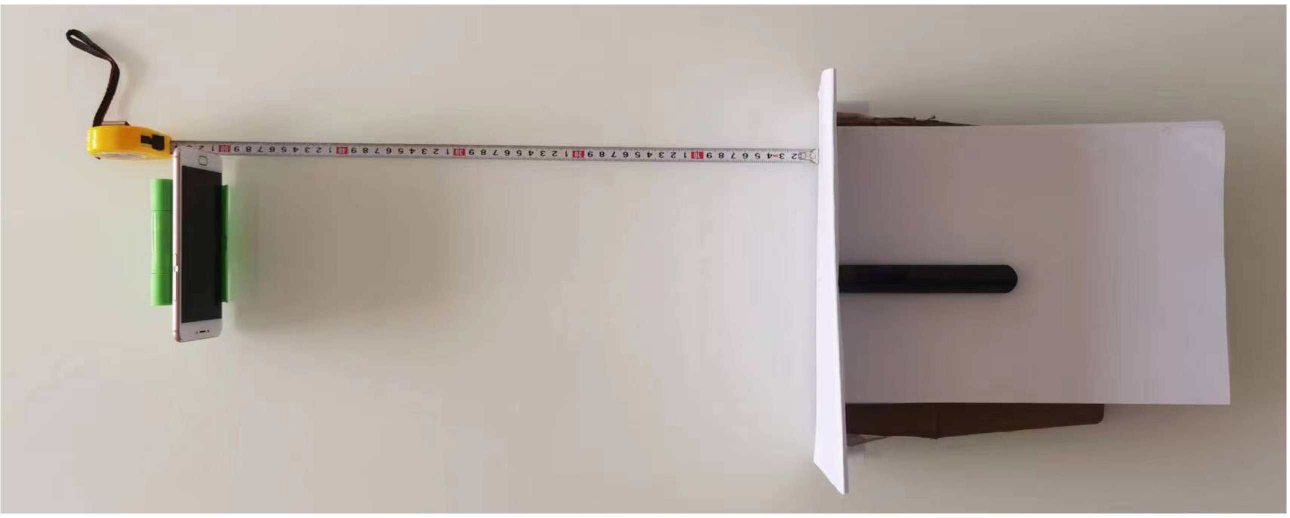


**Figure 4.4 Top view of the experimental platform**

At this point, place the Honor 8 phone on the phone holder, with the phone screen facing the laser. After turning on the laser, a diffraction pattern appears on the display screen, as shown in Figure 4.5. The image is relatively clear and can be further observed.

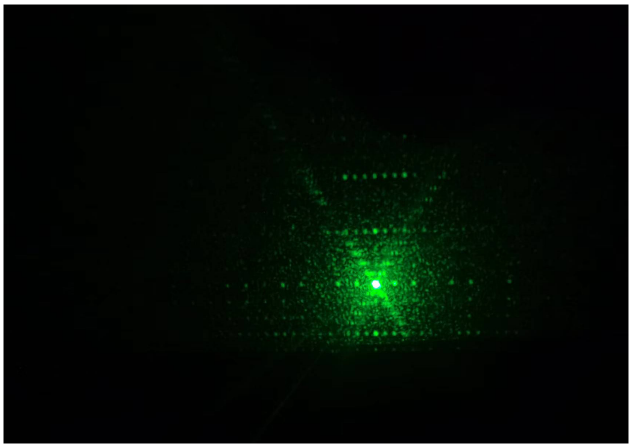


**Figure 4.5 Diffraction pattern of Honor 8 smartphone screen under vertical laser irradiation**

## 4.2 Comparison of Diffraction Patterns of Different Smartphones

Conduct experiments using prepared smartphones, and the diffraction patterns obtained are shown in the following figures.

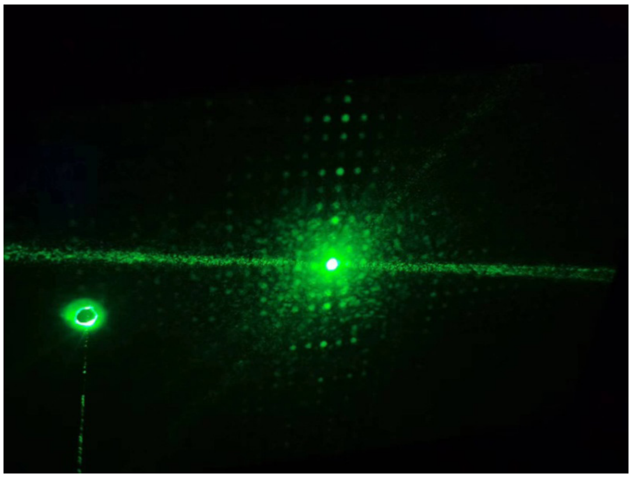


**Figure 4.6 Diffraction pattern of iPhone 7 Plus**

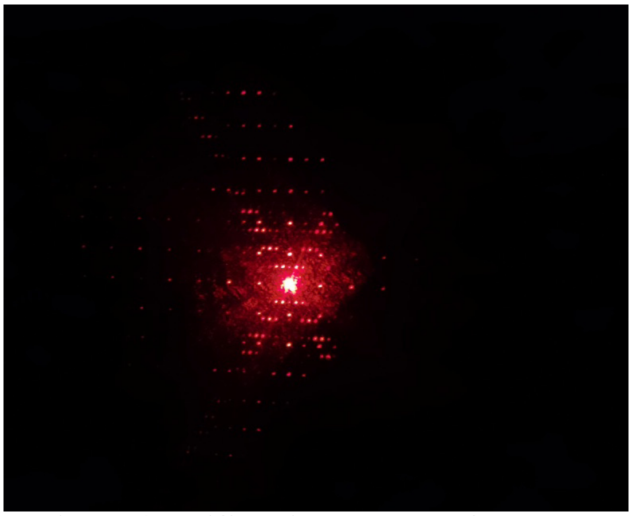


**Figure 4.7 Diffraction pattern of Honor 8**

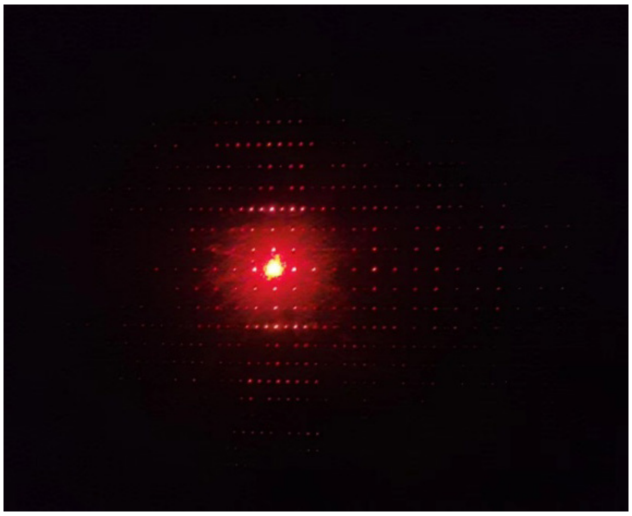


**Figure 4.8 Diffraction pattern of VIVO S9e**

It can be seen that the measured diffraction patterns are very similar to the patterns of the simulation results. In the diffraction pattern of Honor 8, the x-type is very obvious, and the brightness of the central square in the VIVO S9e pattern is higher than around, while the surrounding area is darker. This confirms the rationality of the theoretical function derivation and Fourier transform solutions.

### 4.3 Diffraction Patterns under Bright and Dark Screen Conditions

When the phone screen lights up, the pixels will light up, while when it goes out, the pixels will not emit light. Will the phone's bright and dark screens interfere with the diffraction pattern? In response to this issue, comparative experiments are conducted on the diffraction patterns of the bright screen and the dark screen.

After placing the phone and aligning it with the laser pen, photos of the diffraction patterns are taken in both bright and dark screen states. Due to the presence of three different colors of pixels on the smartphone screen, in order to exclude the influence of light color, i.e. wavelength, red and green laser pens were used for bright and dark screen experiment, respectively.

The above experiment obtained the following diffraction patterns:

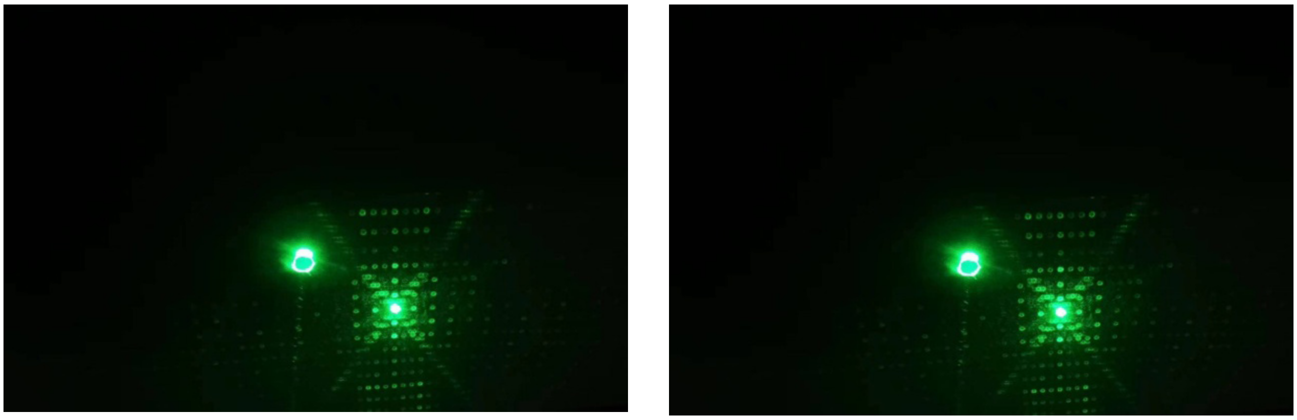


**Figure 4.9 Diffraction patterns of Honor 8 bright and off screens under green light**

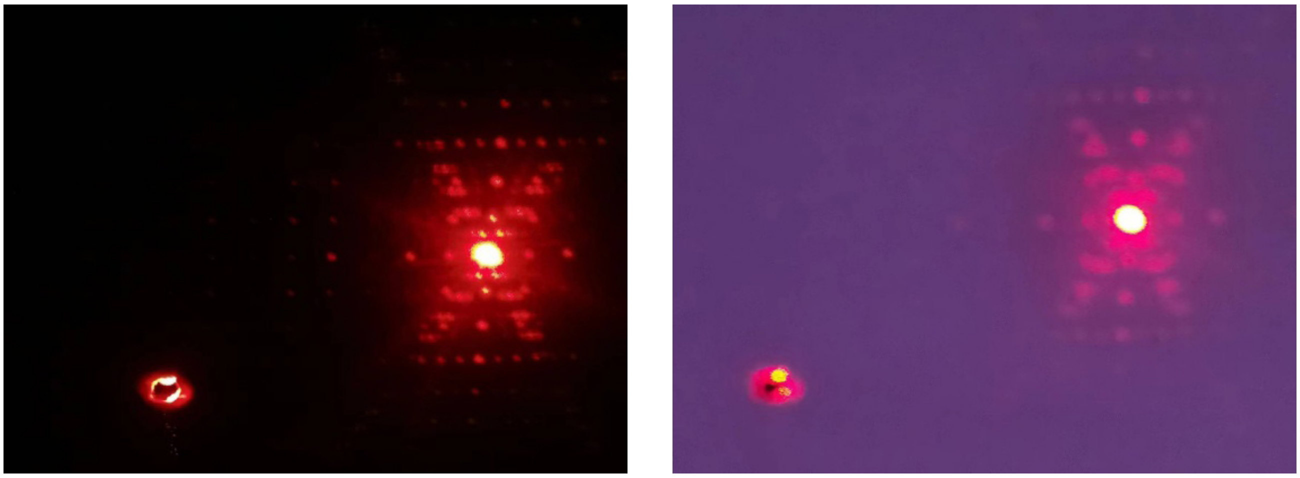


**Figure 4.10 Diffraction patterns of Honor 8 bright and off screens under red light**

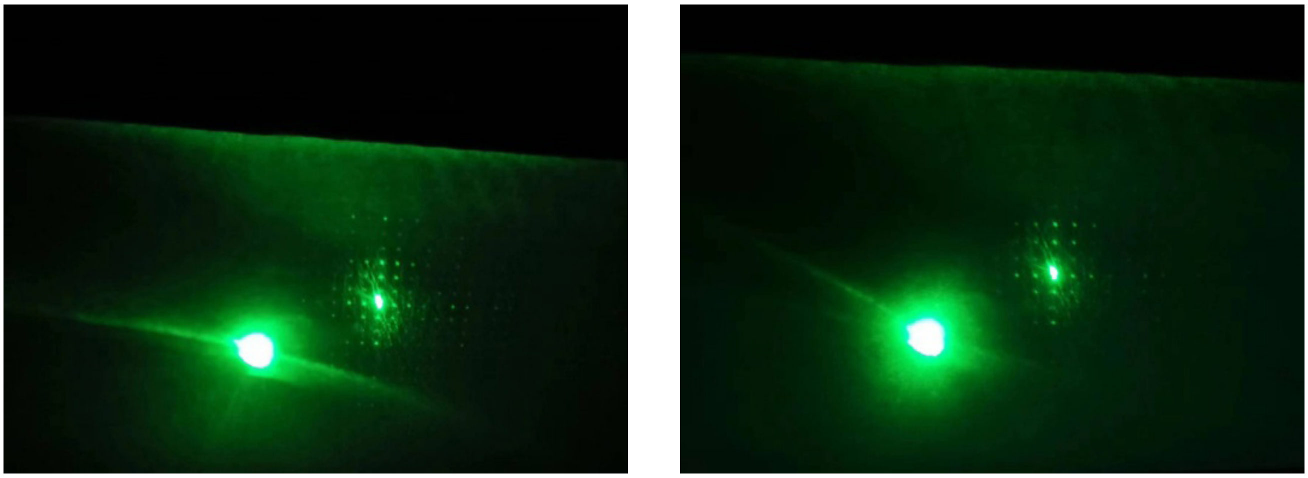


**Figure 4.11 Diffraction pattern of iPhone 7 Plus on and off screen under green light**

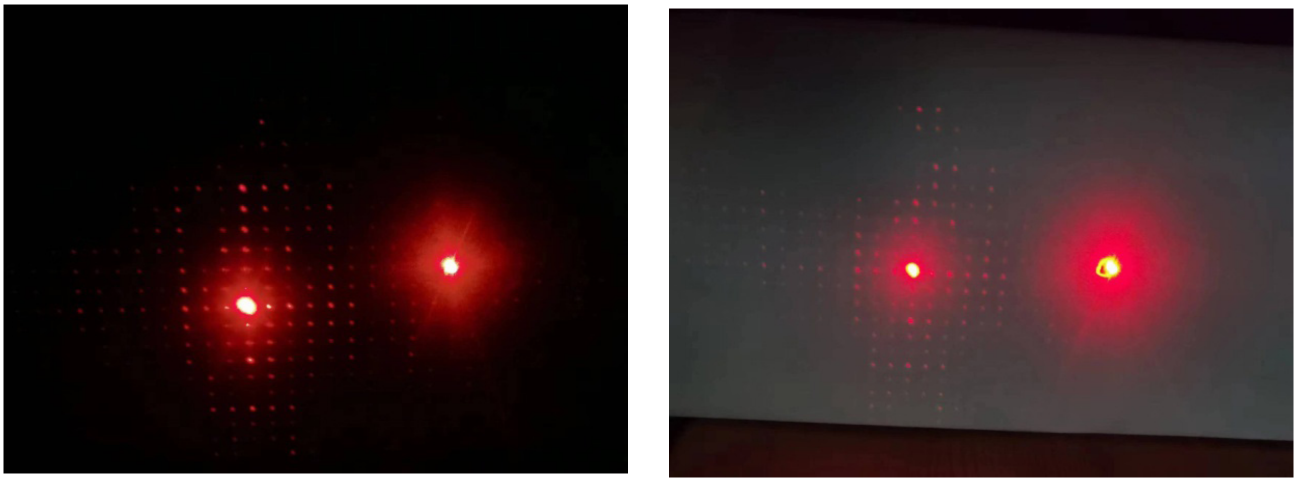


**Figure 4.12 Diffraction patterns of iPhone 7 Plus on and off screen under red light**

It can be seen that regardless of the wavelength of laser, the diffraction patterns of the same phone in both the bright and off screen states are the same, indicating that the bright and dark screen states will not affect the diffraction patterns. By visual inspection, the diffraction image generated by green light is clearer.

### 4.4 Effect of Incident Light Angle on Diffraction Pattern

According to the grating equation, the angle of incident light will affect the diffraction pattern. Next, this effect will be verified through experiments, while Vivo S9e and iPhone7 Plus will be selected as representatives of OLED and LCD screens.

The specific approach is as follows:

(1) Measure the diffraction pattern when the angle of the incident light is 0 degree. Using an experimental platform similar to Figure 4.1, it is necessary to place the protractor in front of the smartphone bracket. The zero line of the protractor coincides with the lower edge of the phone, with the midpoint of the zero line facing the center of the lower edge of the phone. The display screen and the smartphone screen are spaced 50cm apart and parallel to each other, and the laser generated by the laser pen is directed vertically towards the display screen. Open the red laser pen, observe the diffraction pattern on the display screen in the dark, and take photos to record. Replace with a green laser pen and repeat the experimental process just now.

Replace the phone with an LCD screen phone, turn on the red and green laser pens respectively, repeat the experimental process, observe the diffraction pattern on the display screen, and take photos to record.

(2) Coincident the phone with the scale lines at 30 degrees, 45 degrees, 60 degrees, 120 degrees, 135 degrees, and 150 degrees, and adjust the position and direction of the display screen according to the angle. Observe the diffraction patterns and take photos to record.

**Figure 4.13 Diffraction experimental platform at an incidence angle of 30 degrees (in darkness and sunlight)**

The above experiment obtained the following diffraction patterns:

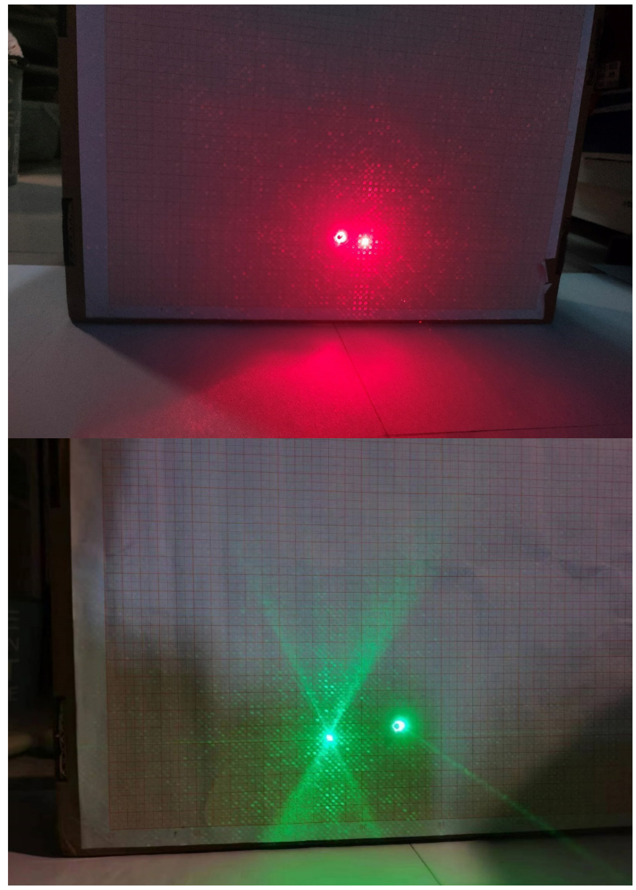


**Figure 4.14 Diffraction pattern of vertically incident OLED screen**

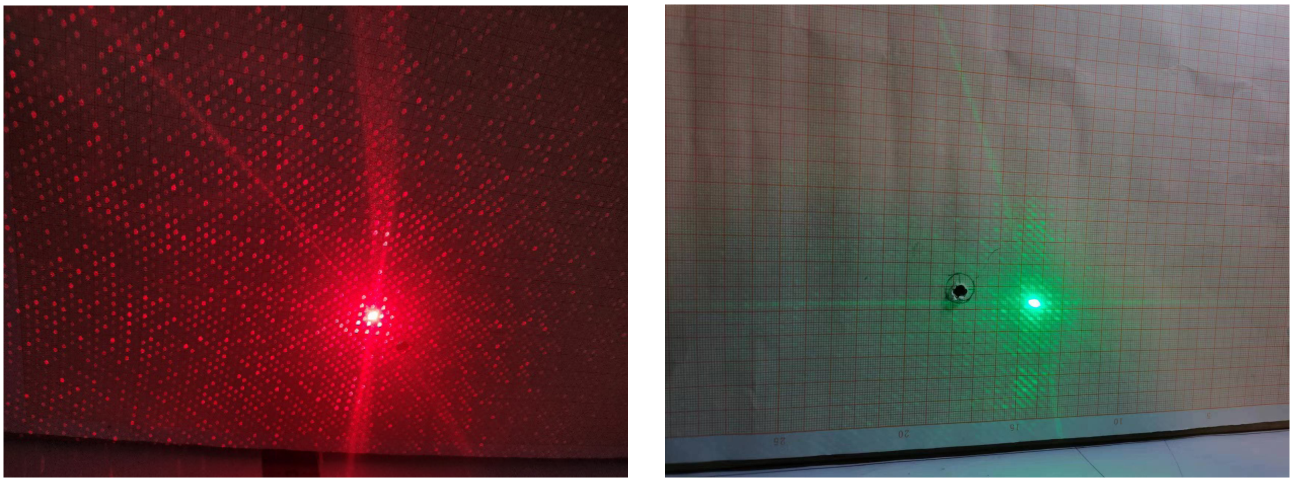


Figure 4.15 Diffraction pattern of OLED screen when laser is incident at 30 degrees to the right

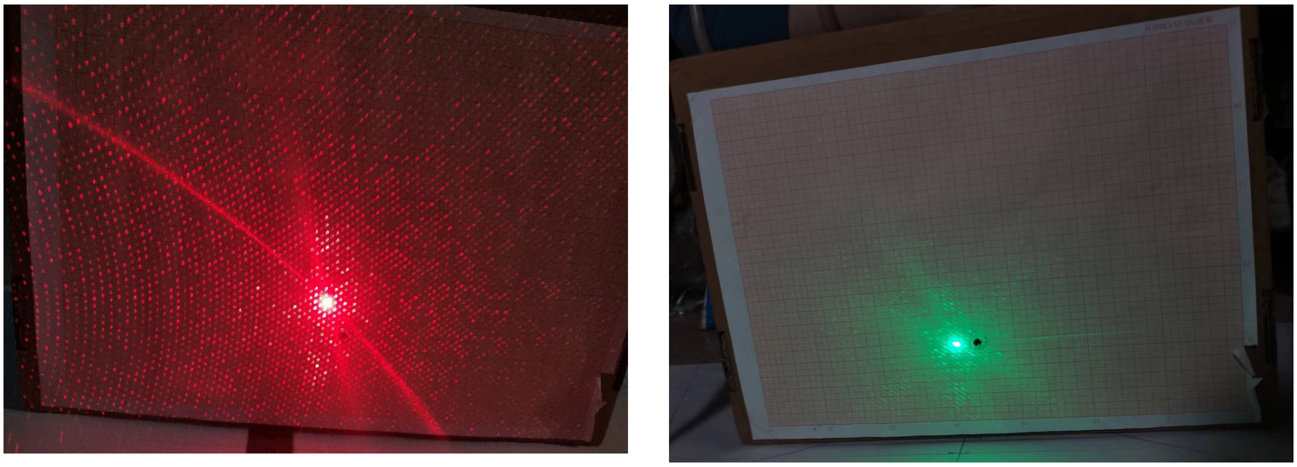


Figure 4.16 Diffraction pattern of OLED screen when laser is incident 45 degrees to the right

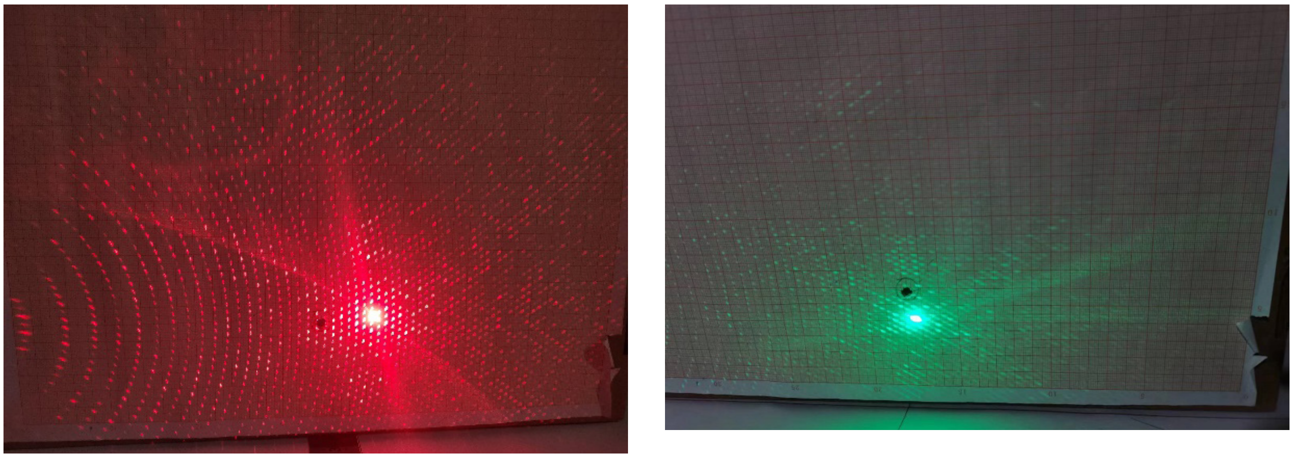


Figure 4.17 Diffraction pattern of OLED screen when laser is incident at 60 degrees to the right

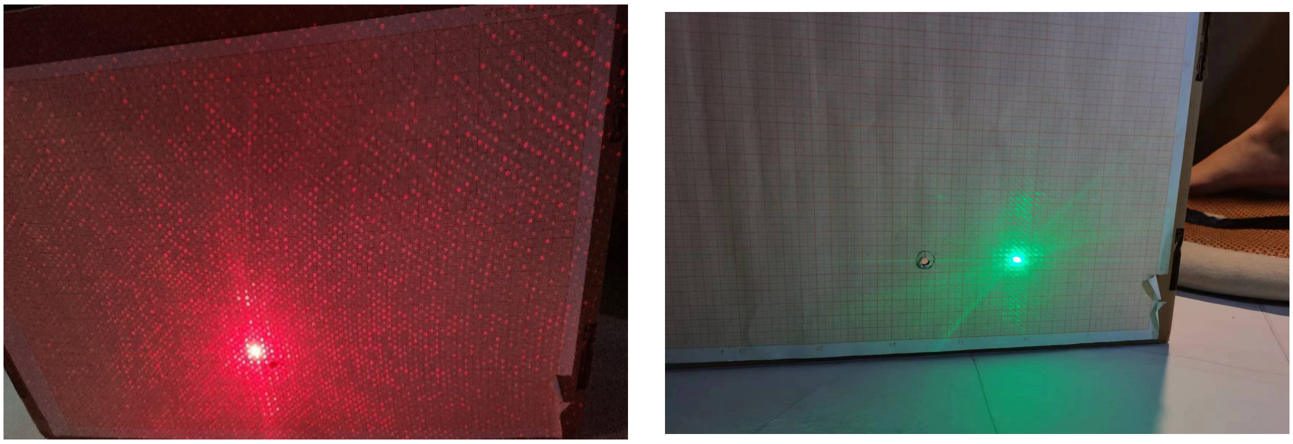


**Figure 4.18 Diffraction pattern of OLED screen when laser is incident 30 degrees to the left**

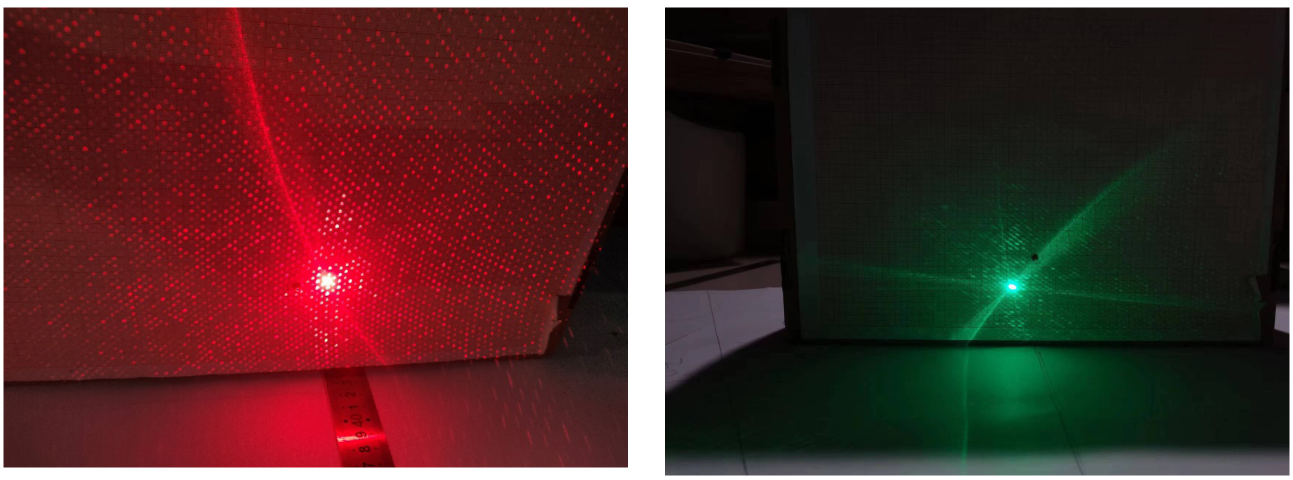


**Figure 4.19 Diffraction pattern of OLED screen when laser is incident at a 45 degree left deviation**

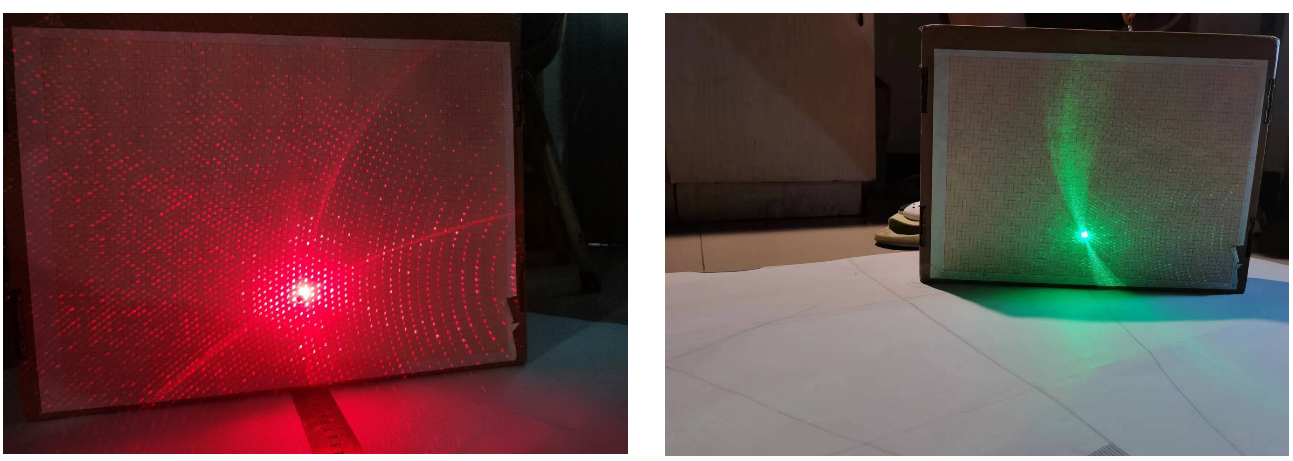


**Figure 4.20 Diffraction pattern of OLED screen when laser is incident at a left deviation of 60 degrees**

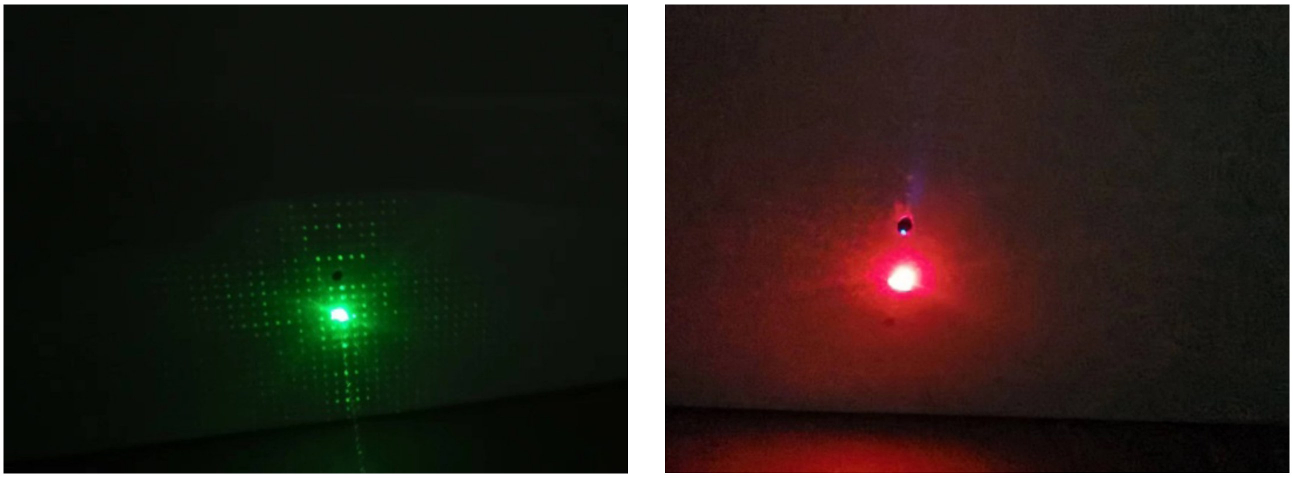


**Figure 4.21 Diffraction pattern of LCD screen under vertical laser incidence**

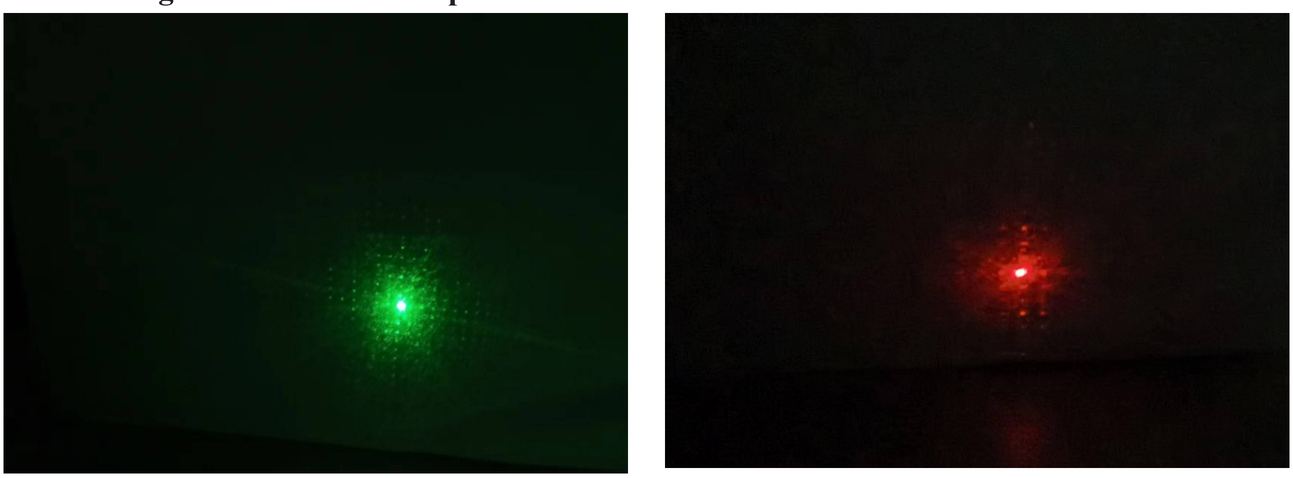


**Figure 4.22 Diffraction pattern of LCD screen (using iPhone 7 plus as an example) when laser is incident at 30 degrees to the right**

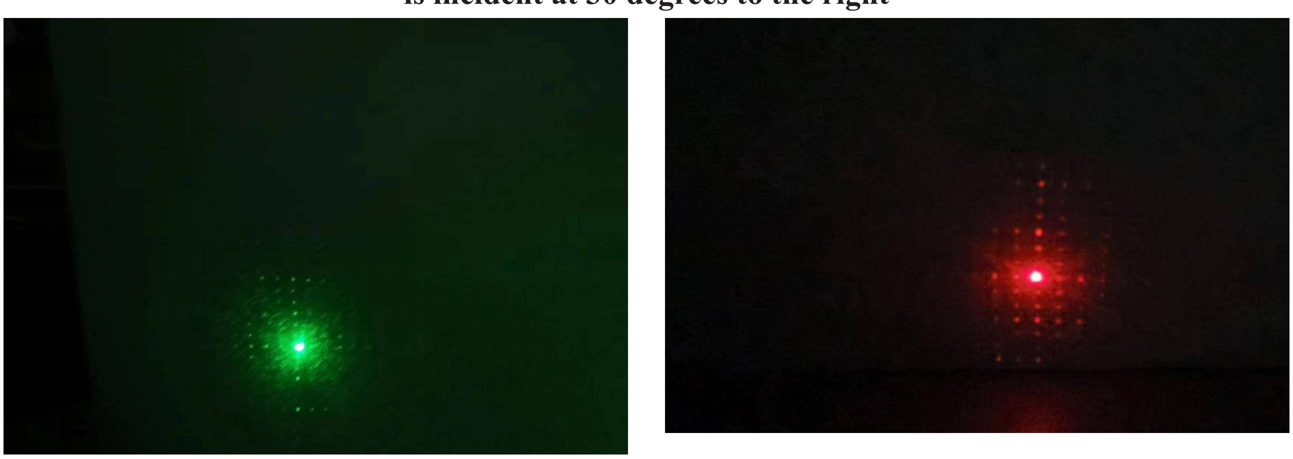


**Figure 4.23 Diffraction pattern of LCD screen (using iPhone 7 plus as an example) when laser is incident 45 degrees to the right**

Figure 4.24 Diffraction pattern of LCD screen (using iPhone 7 plus as an example) when laser is incident at 60 degrees to the right

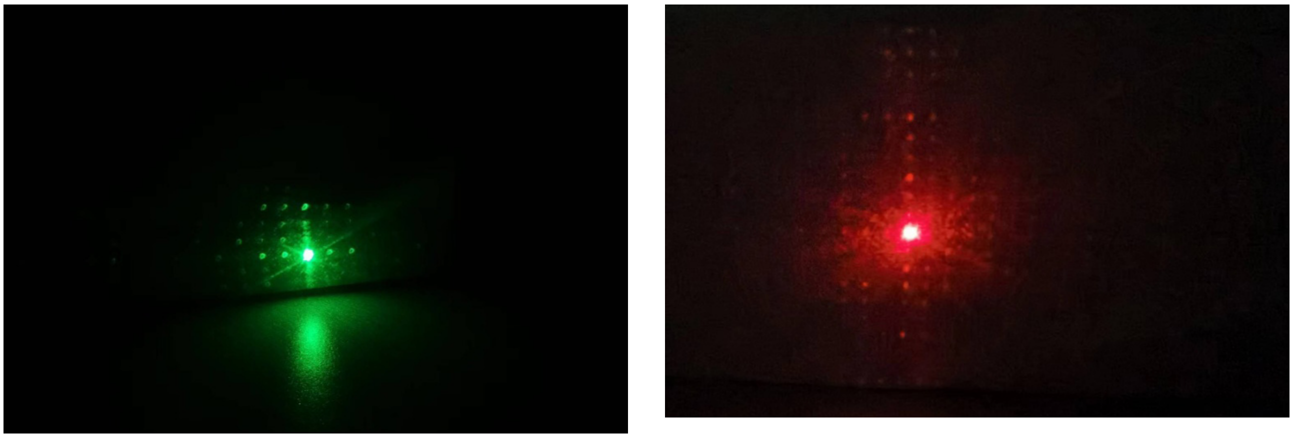


Figure 4.25 Diffraction pattern of LCD screen (using iPhone 7 plus as an example) when laser is incident 30 degrees to the left

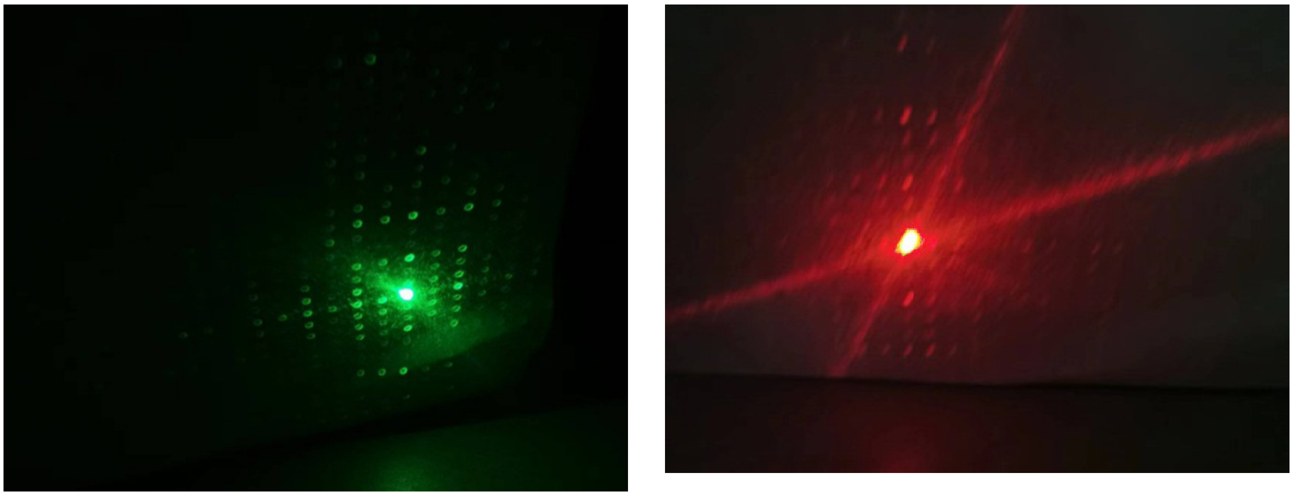


Figure 4.26 Diffraction pattern of LCD screen (using iPhone 7 plus as an example) when laser is incident 45 degrees to the left

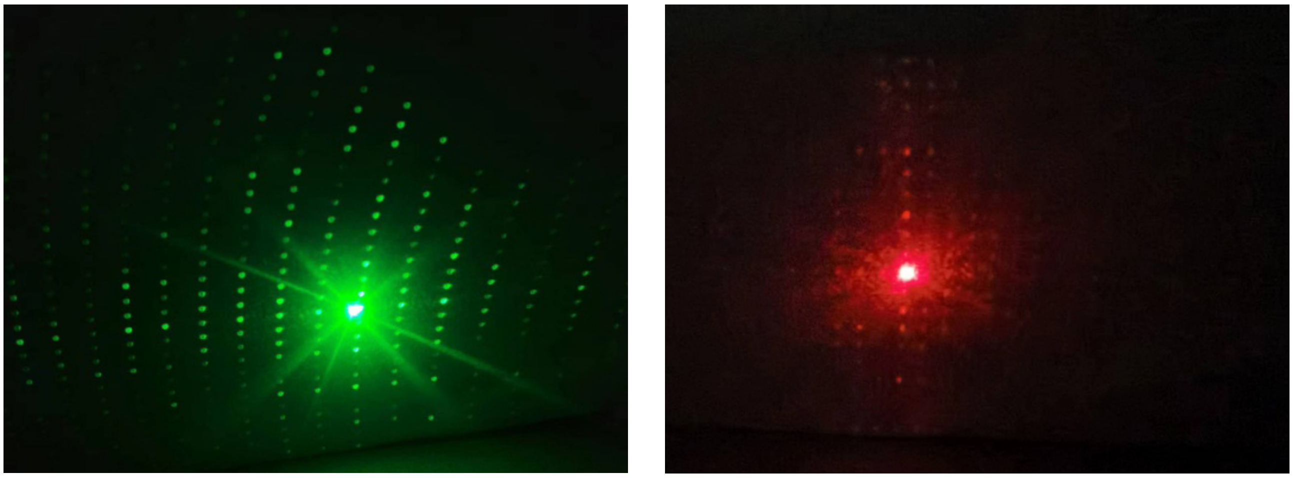


**Figure 4.27 Diffraction pattern of LCD screen (using iPhone 7 plus as an example) when laser is incident at a left deviation of 60 degrees**

In order to measure the relevant data of the diffraction pattern, a paper with a scale is fixed at the display screen. In the diffraction pattern of laser incidence at different angles, the central bright spot is taken as the coordinate origin, the horizontal axis is taken as the x axis, and it is positive to the right and negative to the left. Record the coordinates of three bright spots on the x axis, with the coordinate origin as the midpoint, to the left and right respectively (using red laser incidence as an example):

**Table 4.1 OLED Screen Diffraction Pattern Data for Red Laser Incidence**

| Incident angle/° | Location coordinates/(cm) | | | | | | | $\bar{\Delta x}$ |
|---|---|---|---|---|---|---|---|---|
| -60 | -1.62 | -1.20 | -0.57 | 0.00 | 0.54 | 1.08 | 1.58 | 0.533 |
| -45 | -1.56 | -1.05 | -0.55 | 0.00 | 0.53 | 1.03 | 1.56 | 0.518 |
| -30 | -1.49 | -1.03 | -0.49 | 0.00 | 0.49 | 1.04 | 1.53 | 0.504 |
| 0 | -1.42 | -0.93 | -0.46 | 0.00 | 0.47 | 0.91 | 1.48 | 0.484 |
| 30 | -1.54 | -1.02 | -0.49 | 0.00 | 0.49 | 1.00 | 1.51 | 0.509 |
| 45 | -1.58 | -1.04 | -0.51 | 0.00 | 0.51 | 1.06 | 1.59 | 0.528 |
| 60 | -1.70 | -1.12 | -0.55 | 0.00 | 0.55 | 1.07 | 1.64 | 0.557 |

**Table 4.2 LCD Screen Diffraction Pattern Data for Red Laser Incidence**

| Incident angle/° | Location coordinates/(cm) | | | | | | | $\bar{\Delta x}$ |
|---|---|---|---|---|---|---|---|---|
| -60 | -1.93 | -1.35 | -0.64 | 0.00 | 0.65 | 1.32 | 1.91 | 0.640 |
| -45 | -1.50 | -1.04 | -0.52 | 0.00 | 0.51 | 1.03 | 1.56 | 0.510 |
| -30 | -1.48 | -0.99 | -0.47 | 0.00 | 0.49 | 1.02 | 1.51 | 0.497 |
| 0 | -1.42 | -0.95 | -0.47 | 0.00 | 0.45 | 0.90 | 1.37 | 0.466 |
| 30 | -1.50 | -1.03 | -0.50 | 0.00 | 0.45 | 0.98 | 1.42 | 0.487 |
| 45 | -1.53 | -1.11 | -0.51 | 0.00 | 0.53 | 1.06 | 1.55 | 0.513 |
| 60 | -1.88 | -1.27 | -0.61 | 0.00 | 0.63 | 1.27 | 1.92 | 0.633 |

Plot the average distance $\bar{\Delta x}$ between the two bright spots of the diffraction pattern at different incident angles into a line graph as shown in the following tow figures. It can be observed that as the deflection angle of the incident light increases, $\overline{\Delta x}$ increases, which is mutually verified with theoretical analysis.\[ \]

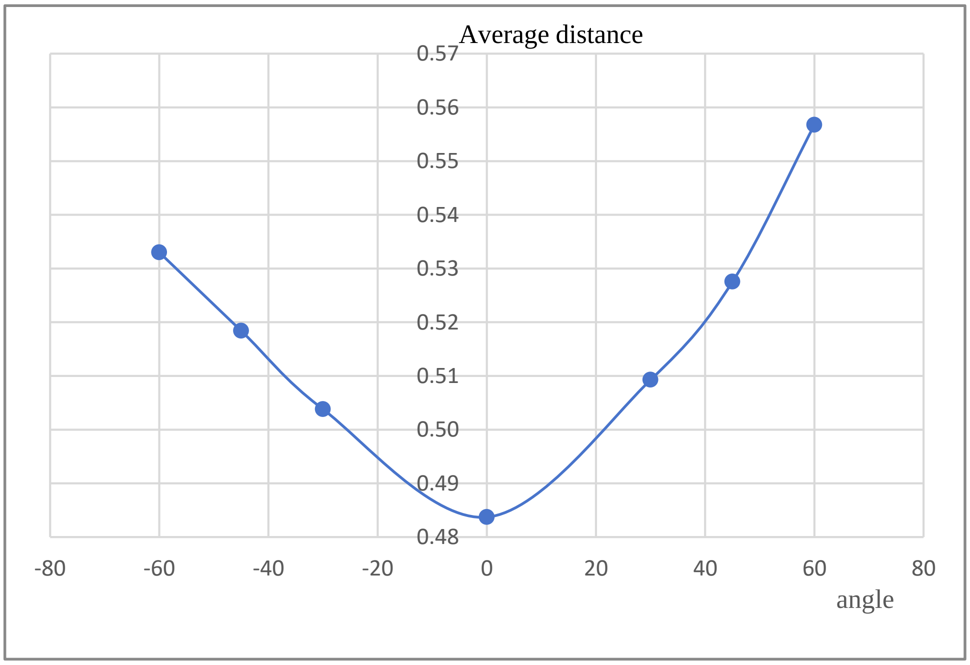



**Figure 4.28 Average distance variation of red laser incident on OLED screen**

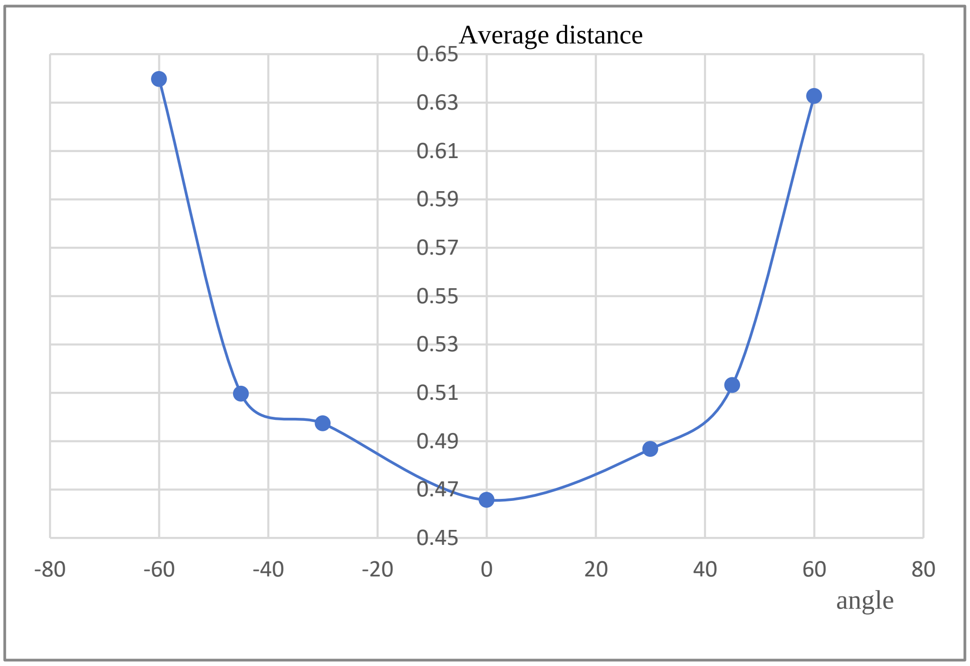



**Figure 4.29 Average distance variation of red laser incident on LCD screen**

## 4.5 Calculation of PPI for Smartphone Screens

The average measurement values of $\Delta x$ obtained from the data in Table 4.1:

$$\overline{\Delta x} = \frac{x_7 - x_1}{6} = 0.484cm \qquad (4\text{-}1)$$

Substituting $\lambda, L, \Delta x$ into equation (3-5) yields an approximate grating constant

$$d = \frac{\lambda L}{\Delta x} = \frac{638\times10^{-9}\times50\times10^{-2}}{0.484\times10^{-2}} = 6.59\times10^{-5}m \quad (4\text{-}2)$$

The measured value of PPI can be obtained:

$$PPI_m = \frac{1}{39.37d} = \frac{1}{39.37\times6.59\times10^{-5}} = 385.38(1/inch) \quad (4\text{-}3)$$

The theoretical PPI value of this model of smartphone is 408 per inch, and the measured error is

$$E = \left|\frac{PPI_m - PPI_r}{PPI_r}\right|\times100\% = \left|\frac{385.38-408}{408}\right|\times100\% = 5.54\% \quad (4\text{-}4)$$

The same method can be used to calculate the PPI of LCD screen phones as 371.05, with an error of 7.45%. The error of both results is relatively small, so it is feasible to use the diffraction pattern of smartphone screens to calculate the PPI of smartphone screens.

V. Conclusion

Through this experiment, the following conclusions can be drawn.

1. With the help of differential element method and definite integral operation, the optical intensity distribution function of a two-dimensional non-uniform grating can be derived as

$$I = A_0^2\cdot\frac{\sin^2(N\frac{\pi}{\lambda}d\sin\theta)}{\sin^2(\frac{\pi}{\lambda}d\sin\theta)}\cdot[\frac{\sin^2(\frac{\pi}{\lambda}a\sin\theta)}{(\frac{\pi}{\lambda}a\sin\theta)^2}+\frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta)}{(\frac{\pi}{\lambda}b\sin\theta)^2}$$
$$+2\cdot\frac{\sin(\frac{\pi}{\lambda}a\sin\theta)}{\frac{\pi}{\lambda}a\sin\theta}\cdot\frac{\sin(\frac{\pi}{\lambda}b\sin\theta)}{\frac{\pi}{\lambda}b\sin\theta}\cdot\cos(\frac{\pi}{\lambda}d\sin\theta)]$$

Specifically, when the grating gap width meets certain conditions, the light intensity distribution function can be further decomposed into

$$I_x = A_0^2\cdot\frac{\sin^2(N\frac{\pi}{\lambda}6b\sin\theta)}{\sin^2(\frac{\pi}{\lambda}6b\sin\theta)}\cdot\frac{\sin^2(\frac{\pi}{\lambda}b\sin\theta)}{(\frac{\pi}{\lambda}b\sin\theta)^2}$$
$$\cdot[1+\cos^2(\frac{\pi}{\lambda}b\sin\theta)+2\cdot\cos(\frac{\pi}{\lambda}b\sin\theta)\cdot\cos(\frac{\pi}{\lambda}6b\sin\theta)]$$

This indicates that the reflected light of two-dimensional non-uniform gratings is influenced by a combination of single hole diffraction, porous interference, and the influence between gratings.

2. The simulation patterns of OLED and LCD screens were drawn using MATLAB, and compared with the experimental results, the rationality of the theoretical derivation is confirmed.

3. The brightness of the smartphone screen does not affect the diffraction pattern of the grating.

4. By using the diffraction pattern of smartphone gratings, the PPI of smartphone screens can be measured with high accuracy.

## 5. Application Assumption:

(1) Use the morphology of the diffraction pattern to determine the pixel arrangement and phone model of the smartphone screen.

Through the previous theoretical analysis, simulation, and experimental research, it can be seen that the grating diffraction patterns of OLED and LCD screens are different. Even for the same type of screen, such as Honor 8 and iPhone 7 Plus, which are both LCD screens, their pixel arrangements are different, so there are still some differences in the grating diffraction patterns. By utilizing this difference, the morphology of the diffraction pattern can be used to determine the pixel arrangement of the phone screen and possible phone models. The specific approach is to collect the grating diffraction patterns of various smartphones to form a library first, then collect the grating diffraction patterns of a smartphone with unknown pixel arrangement, preprocess the pattern, extract its features, and then match it with the grating diffraction patterns in the library, ultimately identifying the display mode of the smartphone screen and the model of the phone.

(2) Use diffraction patterns to determine the quality of smartphone screens.

Through the pixel distribution map of the screen under the microscope, it can be seen that the pixel arrangement of various smartphones' screens has a certain pattern, forming a two-dimensional grating. Therefore, by using the laser to irradiate the screen, their respective grating diffraction patterns are formed. If there are some pixel issues on the screen of a certain smartphone, it will affect the structure of the two-dimensional grating it forms, causing a change of the shape of the grating diffraction pattern it produces. Comparing the collected grating diffraction pattern with the grating diffraction pattern under normal pixel distribution can determine whether there is a quality issue with the detected smartphone screen.

The above application of grating diffraction on smartphone screens is only a preliminary idea, and further research and experiments can be conducted to verify it in the future.

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## Acknowledgements

It can be said that the principles of physics are ubiquitous in life. When I was a child, I felt incredibly magical when I saw the rainbow that appeared after the rain. After learning the relevant physics knowledge, I realized that the reason for the formation of rainbows is due to the reflection and refraction of sunlight when it hits small spherical water droplets in the air. Light has many magical properties and often produces interesting phenomena in daily life. The screens of electronic products around will appear with very beautiful patterns when exposed to light. These patterns are all very beautiful and gorgeous, but directly observing the screen of electronic products cannot see these wonderful patterns. Therefore, I often think about where these patterns come from and what are the reasons for their emergence.

Later on, I learned about the phenomenon of diffraction in physics courses. After consulting materials, it was also learned that many electronic screens have regularly arranged pixel points, which can be regarded as gratings.

After learning about the relationship between smartphone screens and gratings, I have encountered more problems. With these problems in mind, I have conducted research and analysis on smart phone screen gratings through theoretical derivation, software simulation, experimental measurement, and other methods.

This study was completed under the guidance of Professor Chen Qingwei from my school. There are many things to learn and effort to pay throughout the entire research process, but the gains are significant. The experimental part of this study, including the design of the experimental platform, the content and steps of the experiment, and the subsequent paper writing methods, were all completed under the careful guidance of Dr. Chen. When problems such as unclear graphics and difficult readings arised during the experiment, Dr. Chen provides advice and guides the experiment site to help solve the problem. With the help of Dr. Chen as well as my efforts, I overcame various difficulties and ultimately completed this paper. The entire paper work not only cultivated my learning ability, promoted my programming ability and experimental hands-on ability, but also deepened the teacher-student relationship between me and Dr. Chen. Every step of my progress cannot be separated from her guidance and encouragement. I would like to express my deep gratitude to Teacher Chen for his selfless dedication!

Thank you for all the help you provided during the writing process of the paper!

## Appendix 1: Simulation Code for Optical Intensity Formula

```
clc;
clear;
L=0.1;
N=1048;
M=10;
d=15*10^(-5);
a=d/3;
b=d/6;
lambda=500*10^(-9);
H=1;
x=linspace(-L/2,L/2,N);
y=x;
thetax=atan(x/H);
u=pi*b*sin(thetax)/lambda;
v=pi*d*sin(thetax)/lambda;
Ix1=(sin(u)./u).^2;
Ix2=(sin(M*v)./(M.*sin(v))).^2;
Ix3=(1+4.*cos(u).^2+4.*cos(u).*cos(6*u));
Ix=Ix1.*Ix2.*Ix3;
I=Ix'*Ix;
imshow(nthroot(I,3))
colormap gray
axis square;
```

Appendix 2: Simulation Code for Fourier Transform

```
clc;
clear;
fig_rgb=imread('guangshan.png');
fig_gray= rgb2gray(fig_rgb);
[m,n]=size(fig_gray);
for i=1:1:m
for j=1:1:n
if abs(fig_gray(i,j)<=80)
A(i,j)=1;
else
A(i,j)=0;
end
end
end
subplot(1,2,1)
imshow(A)
title('Pixel structure of smartphone');
fft_v = abs(fft2(A));
fft_v = fftshift(fft_v);
subplot(1,2,2)
imshow(nthroot(fft_v/max(max(fft_v)),1));
colormap(hot);
clim([0,0.05]);
title('Diffraction pattern');
```